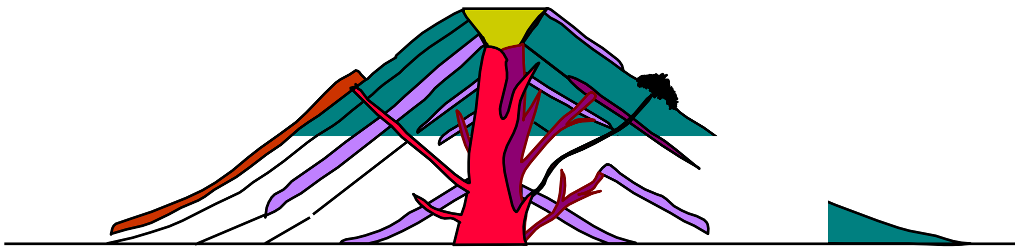


Igneous Petrology

The Earth's Interior

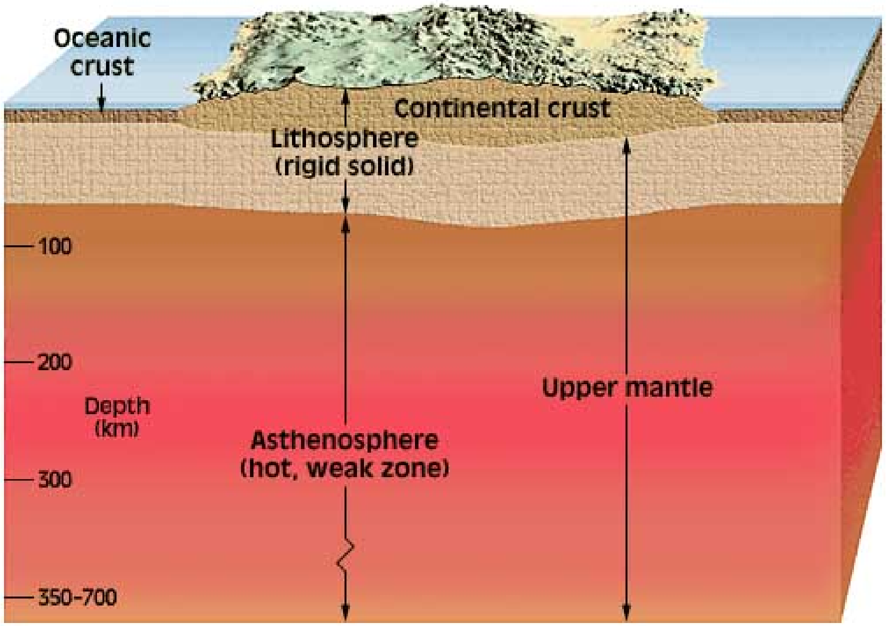
Crust:

Oceanic crust

Thin: 10 km

sediments

- **pillow basalt**
- **massive gabbro**
- **ultramafic (mantle)**



Continental Crust

Thicker: 20-90 km average ~35 km

- **Granodiorite**

The Earth's Interior

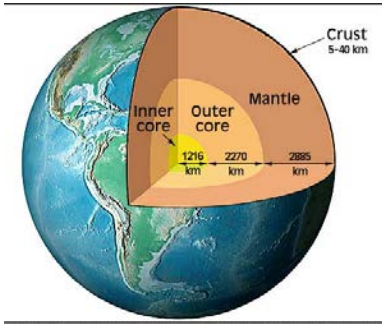
Mantle:

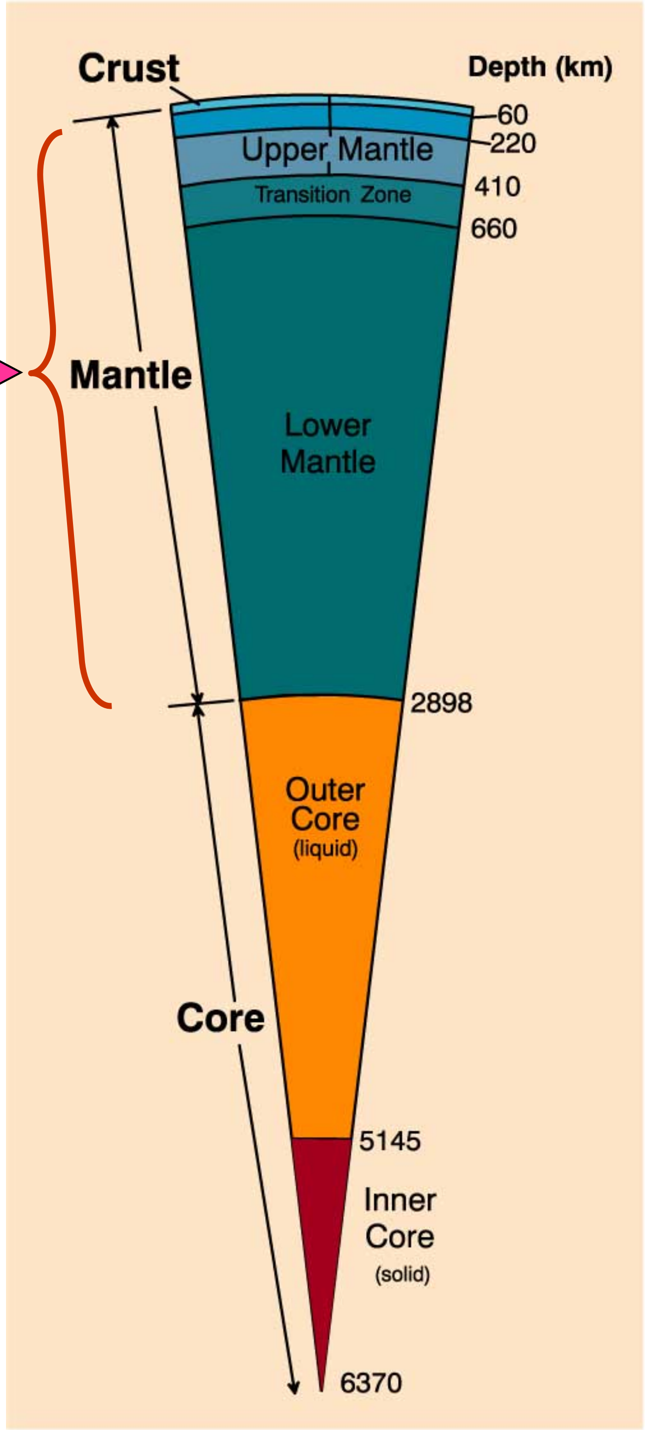
Peridotite (ultramafic)

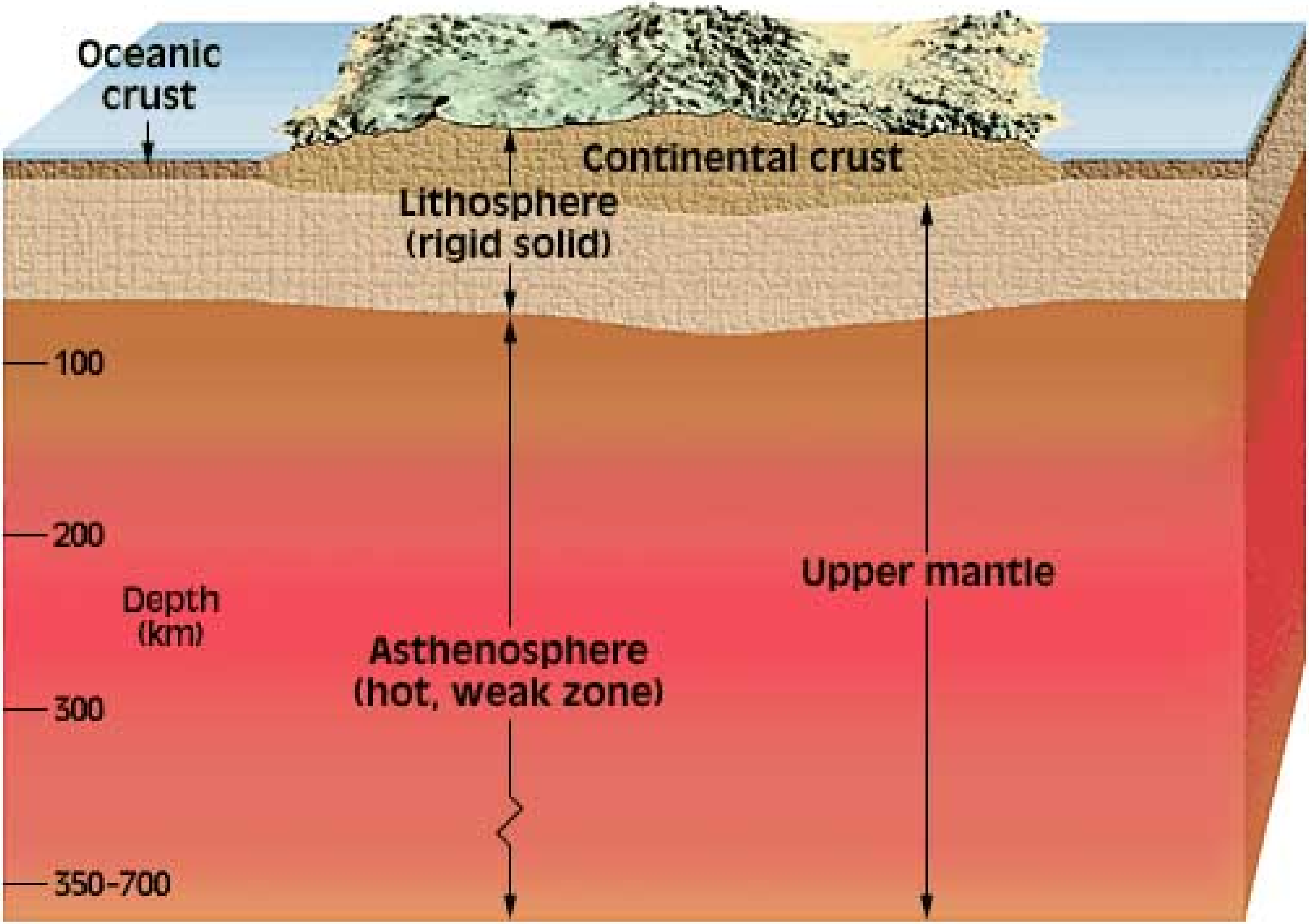
Upper to 410 km (olivine → spinel)

- Low Velocity Layer 60-220 km

Lower Mantle has more gradual velocity increase






Oceanic crust
Continental crust
Lithosphere (rigid solid)
100
200
Depth (km)
300
350-700
Asthenosphere (hot, weak zone)
Upper mantle

The Earth's Interior

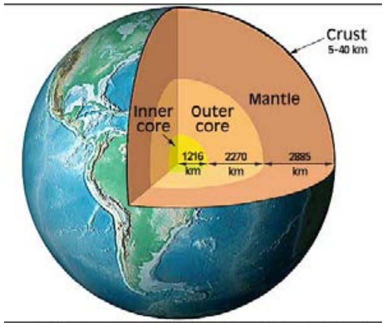
Core:

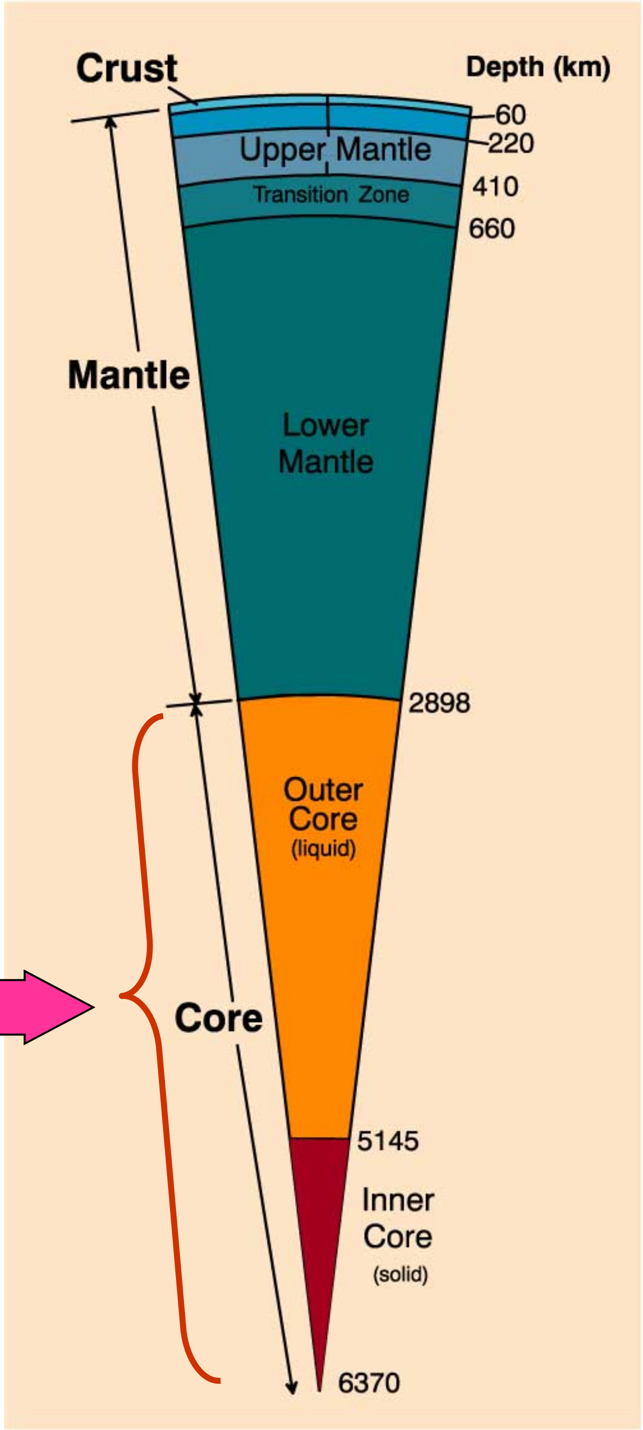
Fe-Ni metallic alloy

Outer Core is liquid

- No S-waves

Inner Core is solid





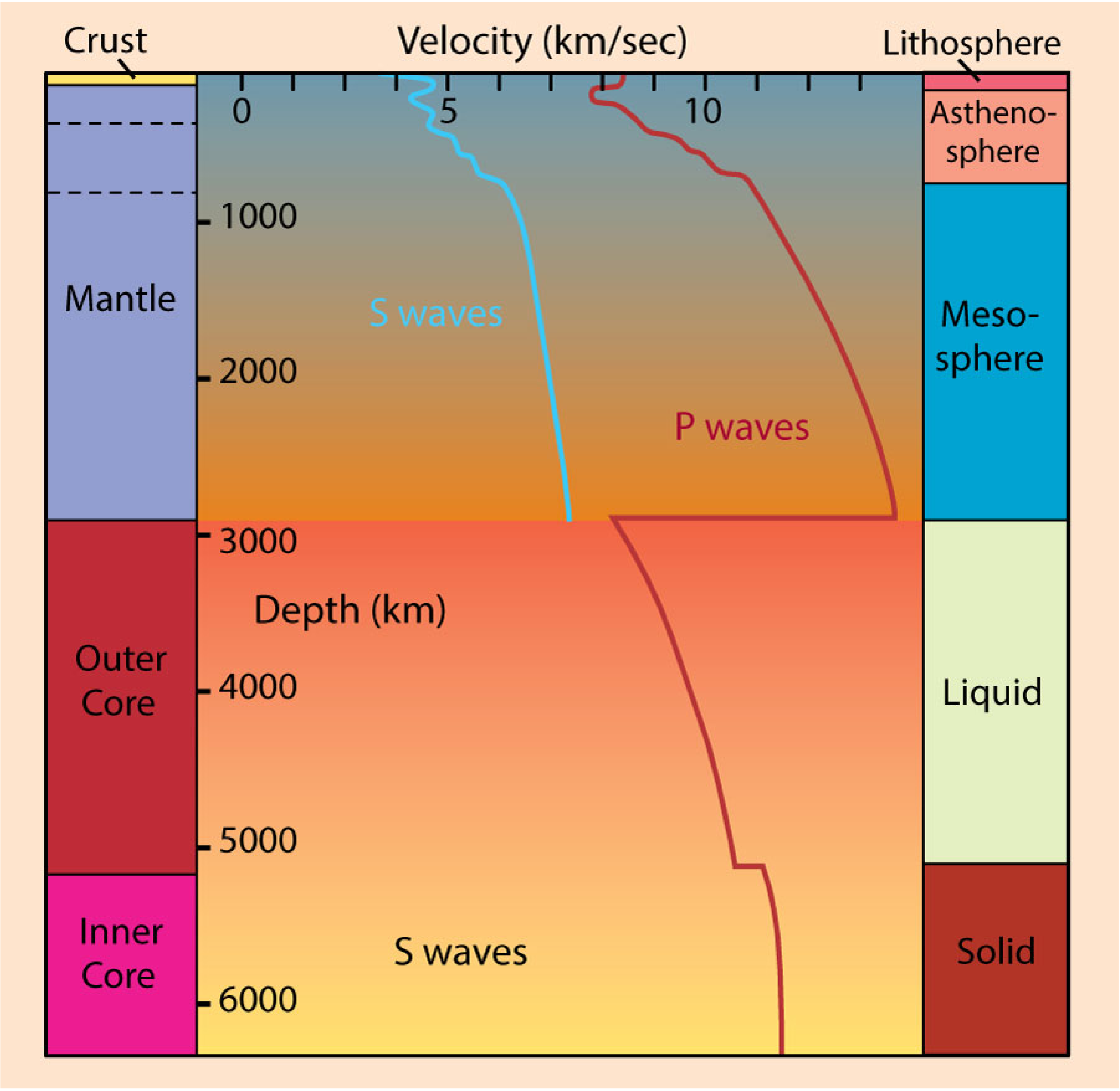


Figure 1.3 Variation in P and S wave velocities with depth. Compositional subdivisions of the Earth are on the left, rheological subdivisions on the right. After Kearey and Vine (1990), *Global Tectonics*. © Blackwell Scientific. Oxford.

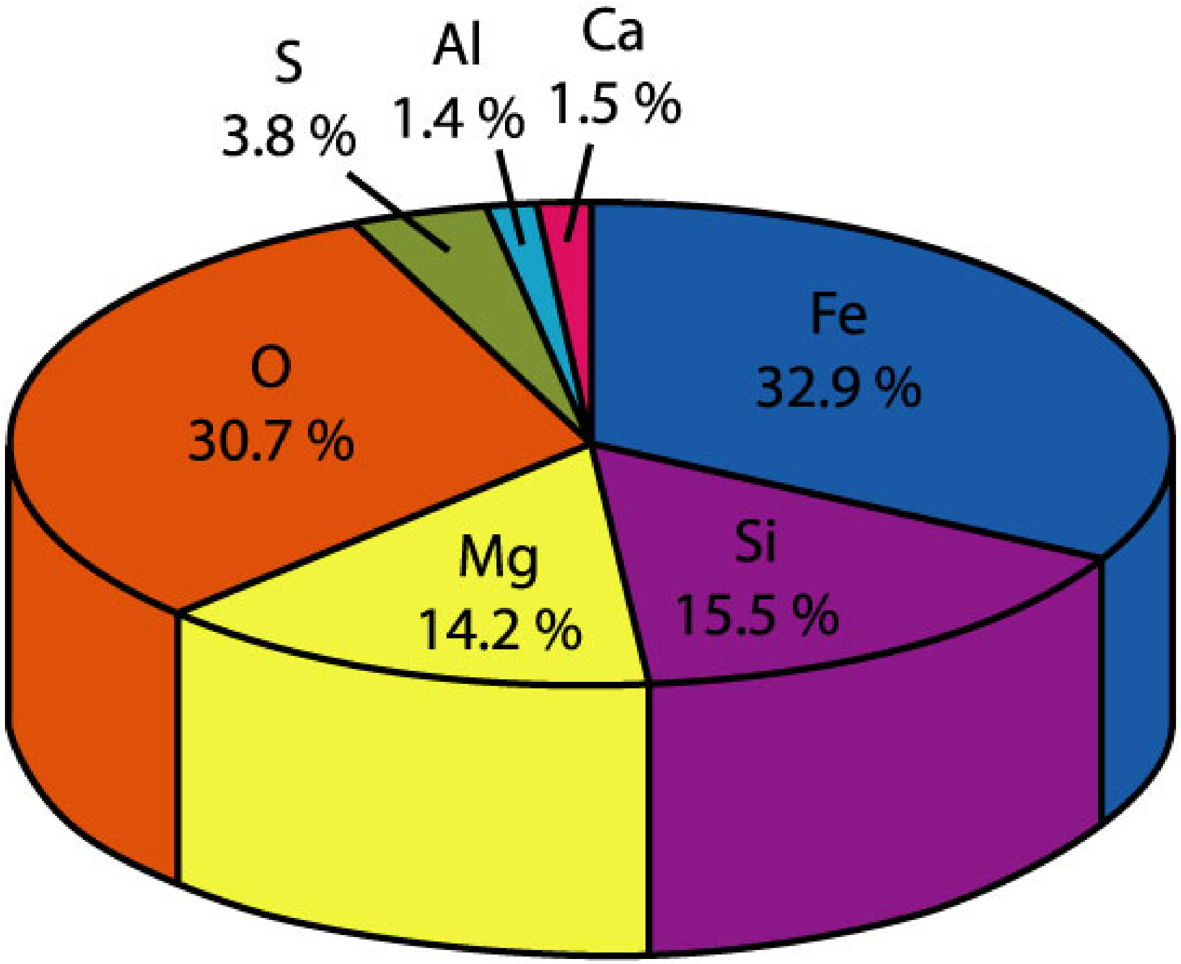


Figure 1.5 Relative atomic abundances of the seven most common elements that comprise 97% of the Earth's mass. An Introduction to Igneous and Metamorphic Petrology, by John Winter , Prentice Hall.

The Pressure Gradient

- P increases = ρgh
- Nearly linear through mantle
- Core:. more rapidly since alloy more dense

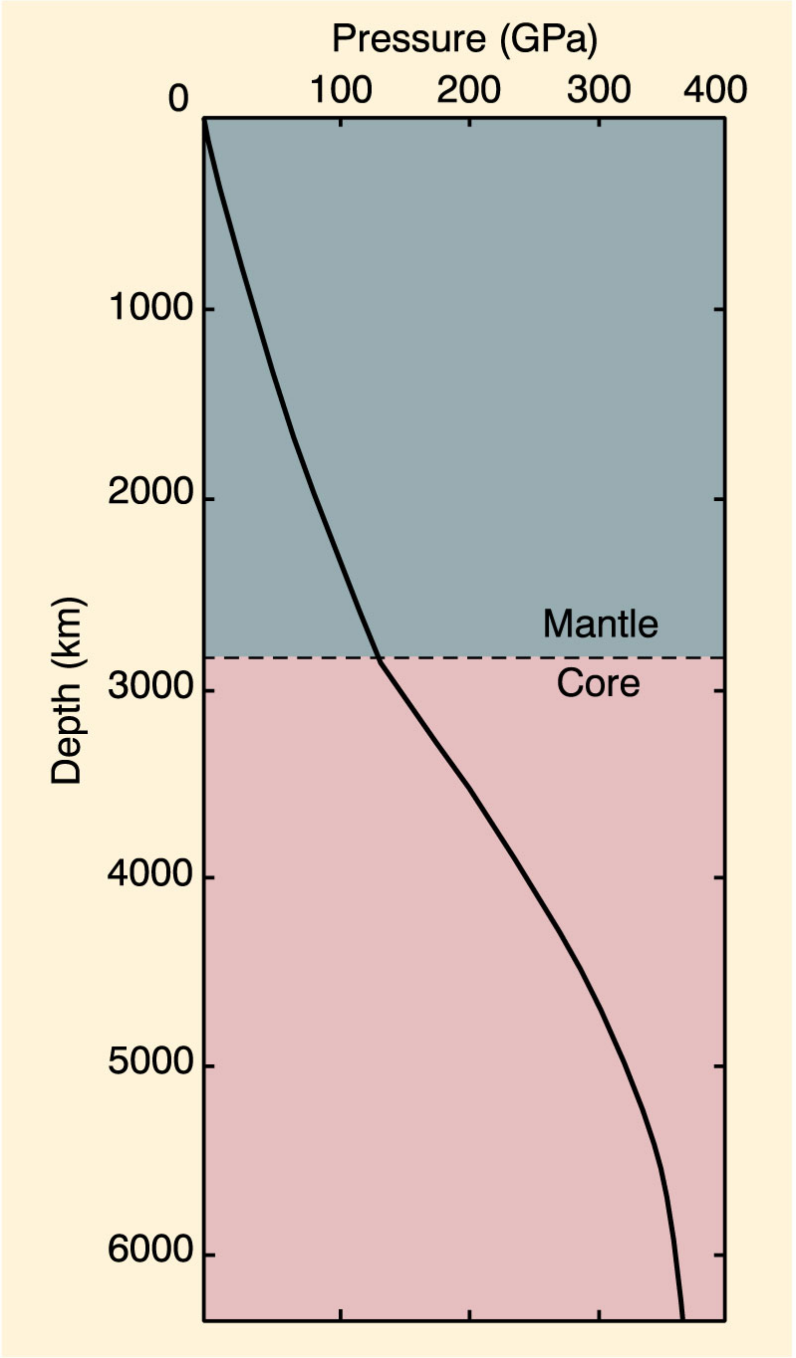


Figure 1.8 Pressure variation with depth. From Dziewonski and Anderson (1981). Phys. Earth Planet. Int., **25**, 297-356. © Elsevier Science.

The Geothermal Gradient

Figure 1.9 Diagrammatic cross-section through the upper 200-300 km of the Earth showing geothermal gradients reflecting more efficient adiabatic (constant heat content) convection of heat in the mobile asthenosphere (steeper gradient in blue)) and less efficient conductive heat transfer through the more rigid lithosphere (shallower gradient in red). The boundary layer is a zone across which the transition in rheology and heat transfer mechanism occurs (in green). The thickness of the boundary layer is exaggerated here for clarity: it is probably less than half the thickness of the lithosphere.

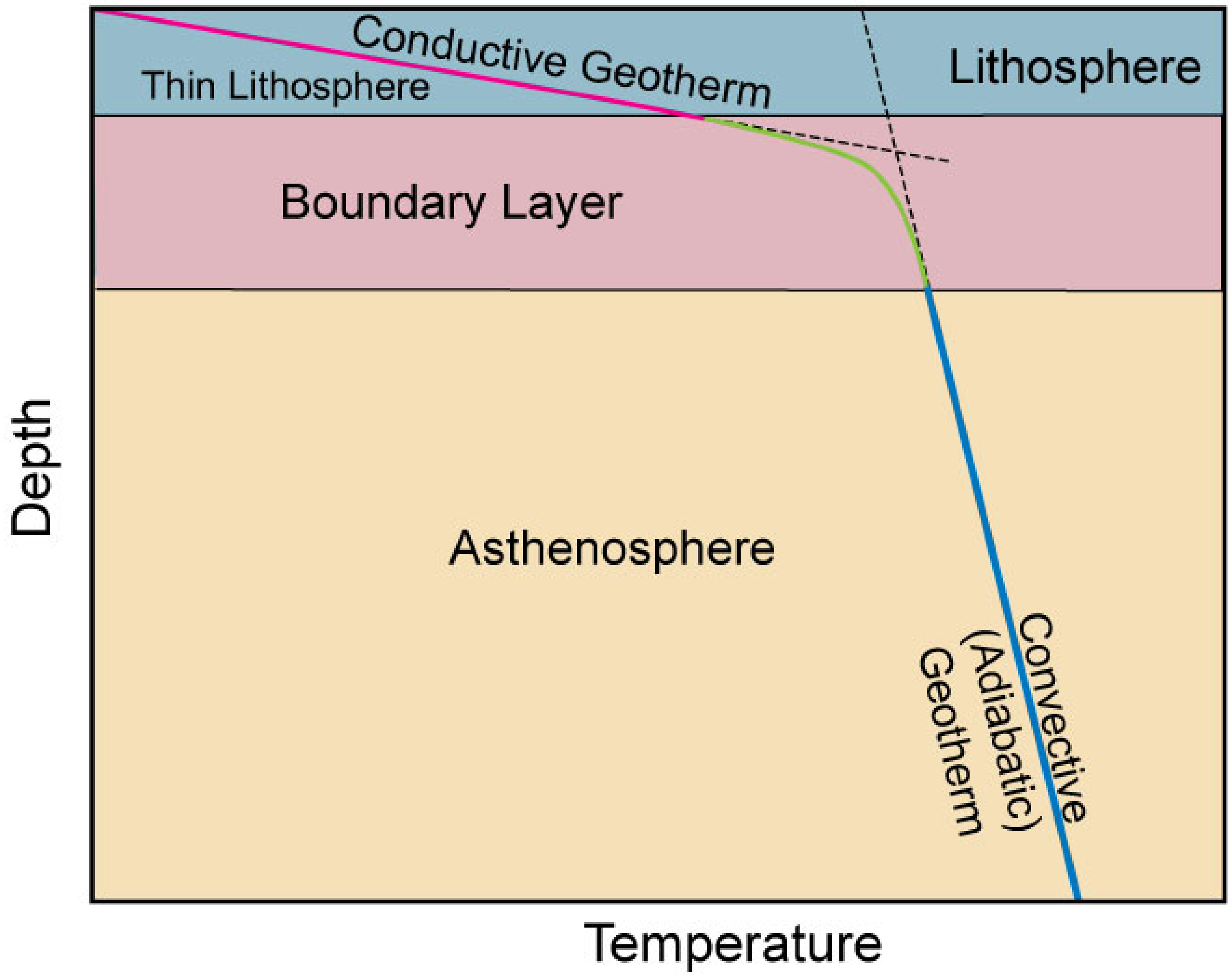
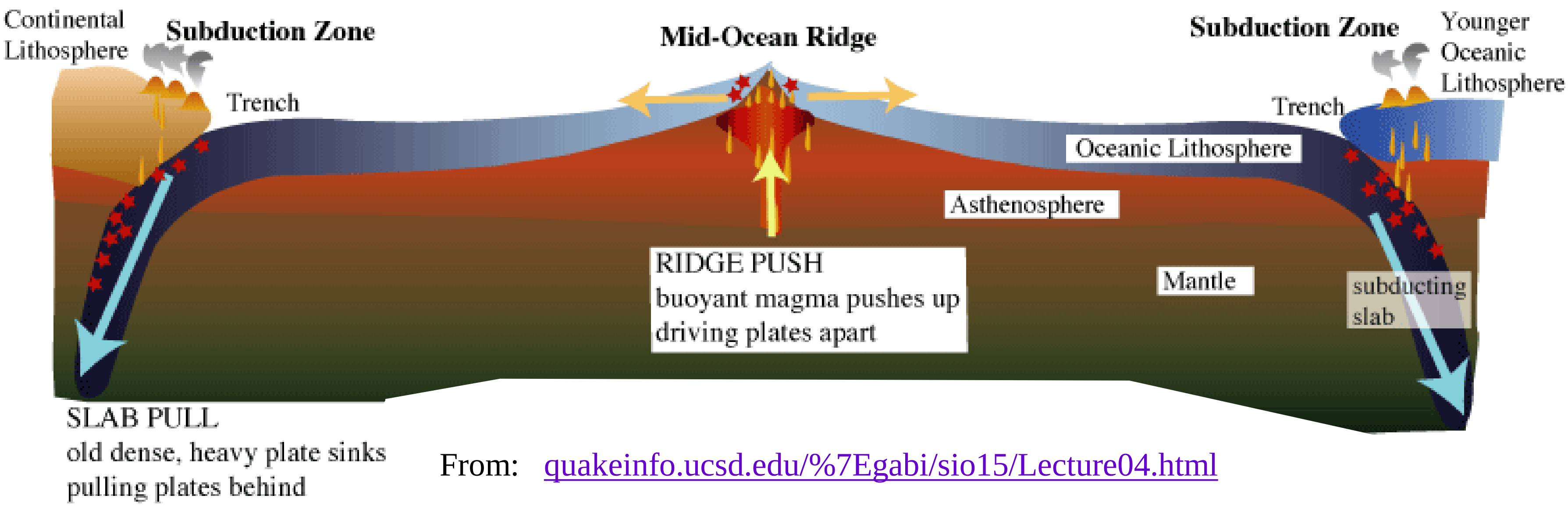


Plate tectonics



From: quakeinfo.ucsd.edu/%7Egabi/sio15/Lecture04.html

The old question of whether convection drives plate tectonics or not

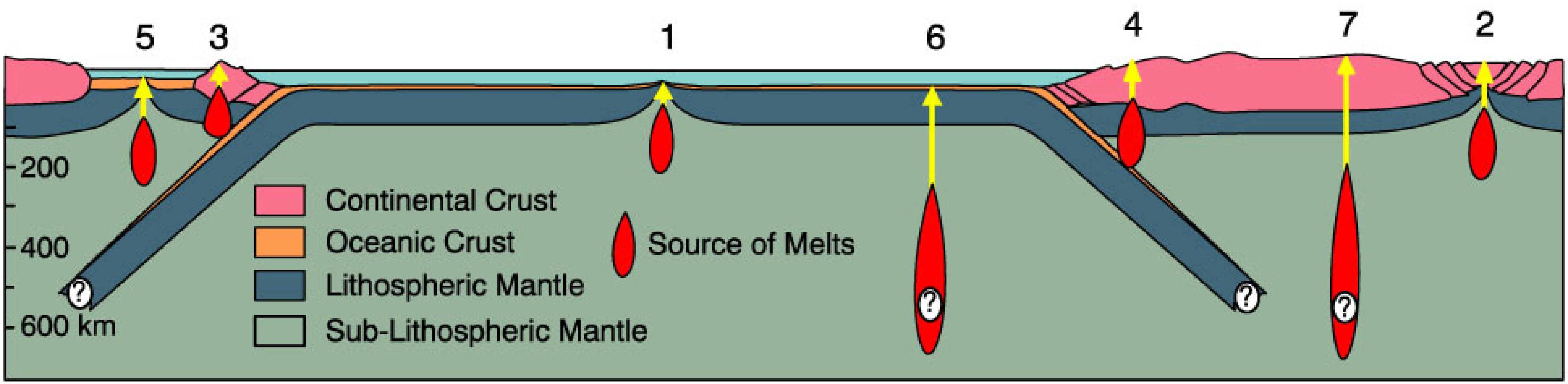
plate tectonics *is* mantle convection.

The core, however, cools by more vigorous convection which heats the base of the mantle by conduction and initiates plumes (lower viscosity)

Plate Tectonic - Igneous Genesis

1. **Mid-Ocean Ridges**
2. **Intracontinental Rifts**
3. **Island Arcs**
4. **Active Continental Margins**
5. **Back-Arc Basins**
6. **Ocean Island Basalts**
7. **Miscellaneous Intra-Continental Activity**

kimberlites, carbonatites, anorthosites...

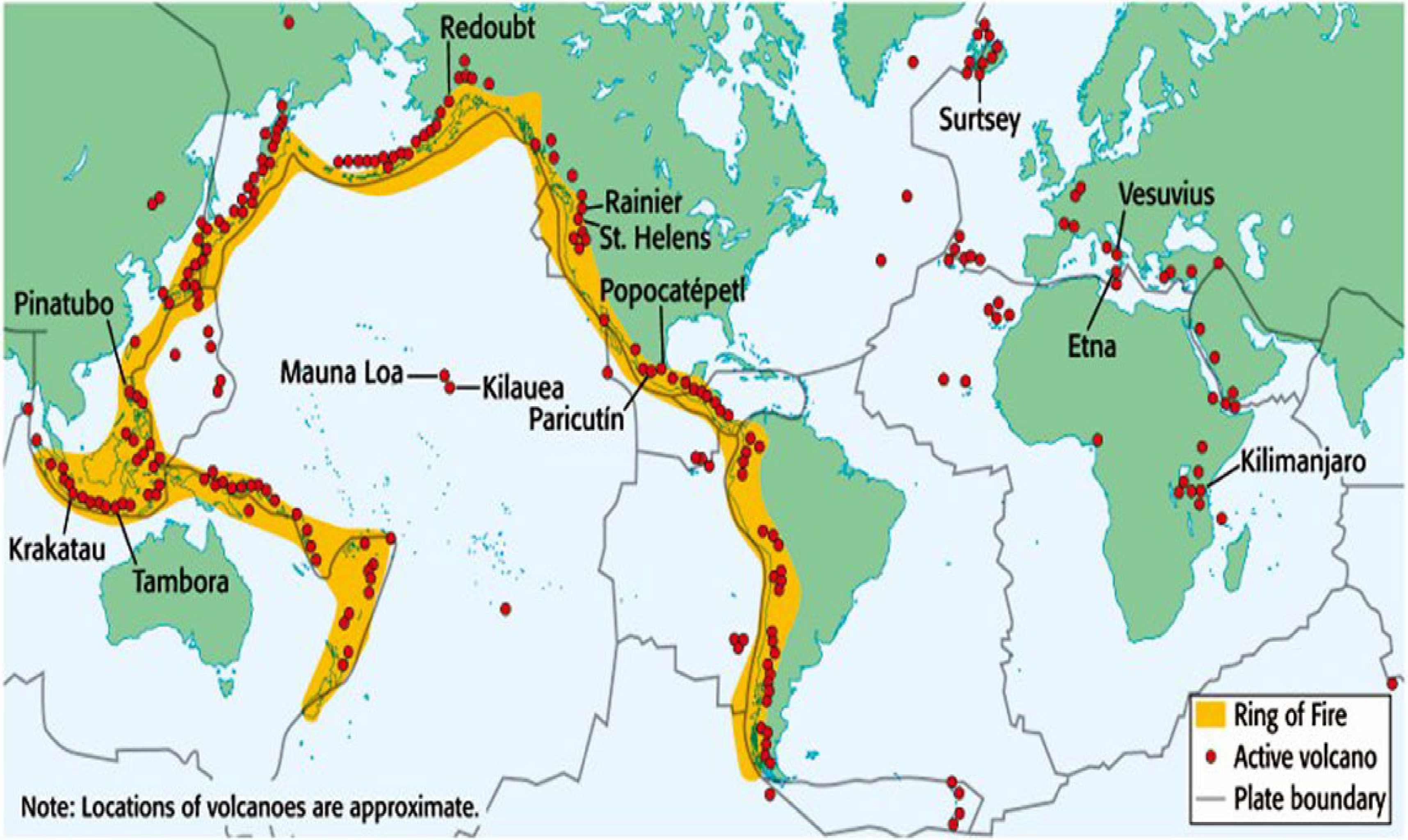


Extrusive Igneous Rocks (Volcanic Eruptions)

- In general, magmas that are generated deep within the Earth begin to rise

- If the the magma has a low viscosity, then the gas can expand easily. When the magma reaches the surface, the gas bubble will simply burst, the gas will easily expand to atmospheric pressure, and a non-explosive eruption will occur, usually as a lava flow.
- If the the magma has a high viscosity, then the gas will not be able to expand easily. Thus, pressure will build inside the gas bubble(s). When the magma reaches the surface, the gas bubbles will have a high pressure inside, which will cause them to burst explosively on reaching atmospheric pressure. This will cause an explosive volcanic eruption.

The Location of Major Volcanoes



A. Non explosive Eruptions

- Non explosive eruptions are favored by low gas content and

  low viscosity magmas (**basaltic to andesitic magmas**).

- **Lava flows** are produced on the surface, and these run like liquids down slope, along the lowest areas they can find. Lava flows produced by eruptions under water are called ***pillow lavas***.







B. Explosive Eruptions

- High viscosity   and high gas content magmas

High viscosity   = (Acidic magmas)

- Explosive bursting of bubbles will fragment the magma into parts of liquid that will cool as they fall through the air.

These solid particles become ***pyroclasts*** (hot fragments)

6.Pyroclats st. :

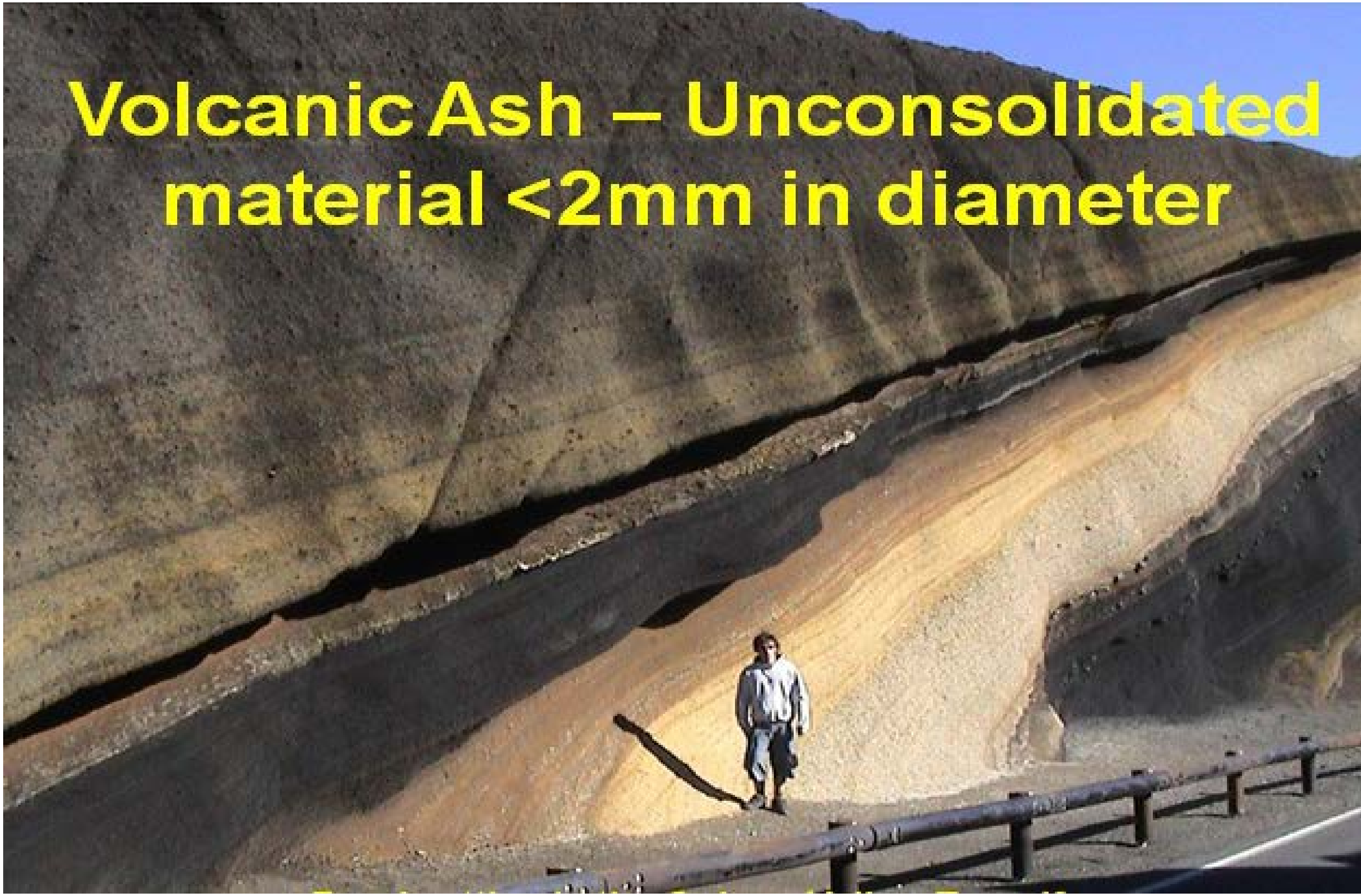
1.Vol. Dust < 0.125mm

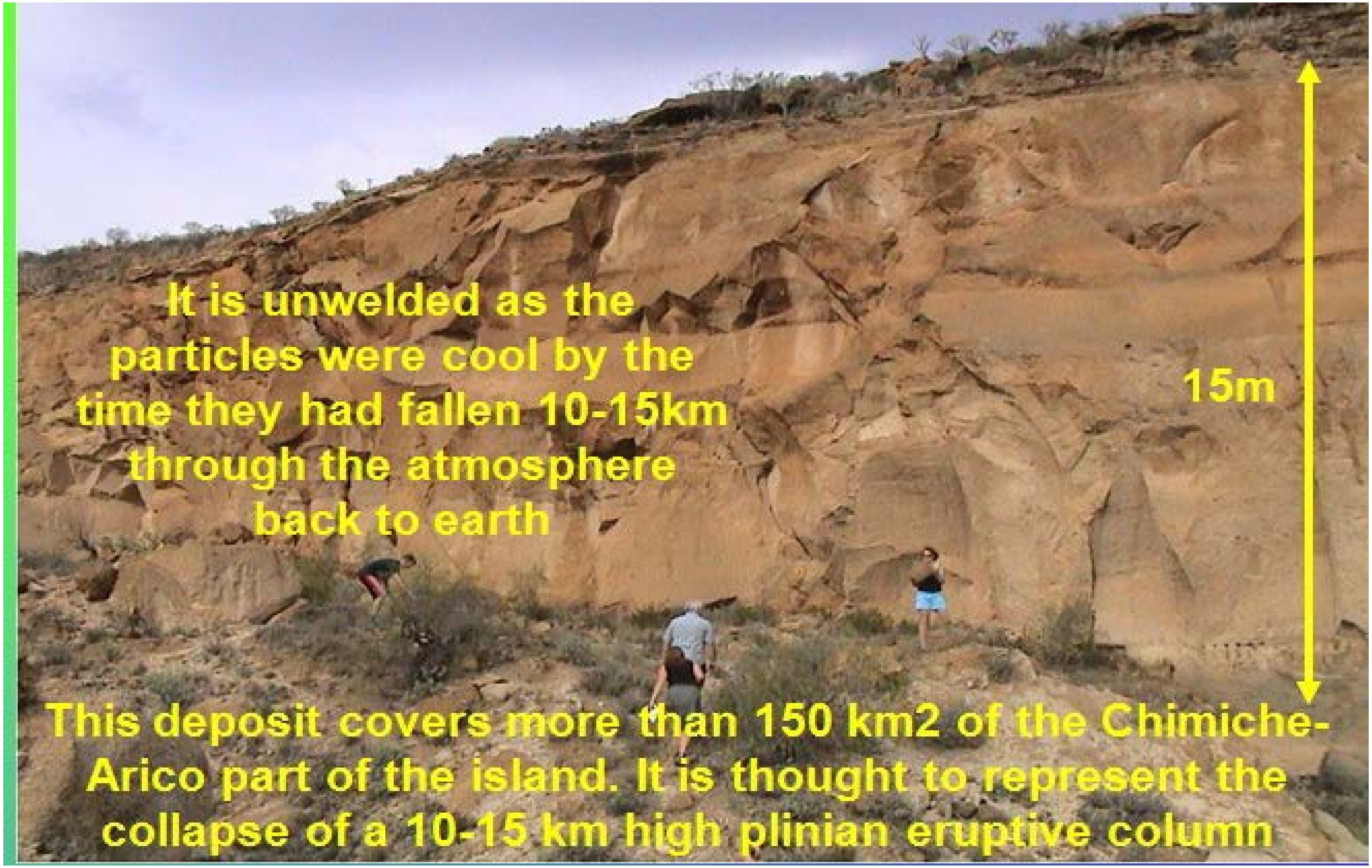
2.Ash: 0.125-2 mm

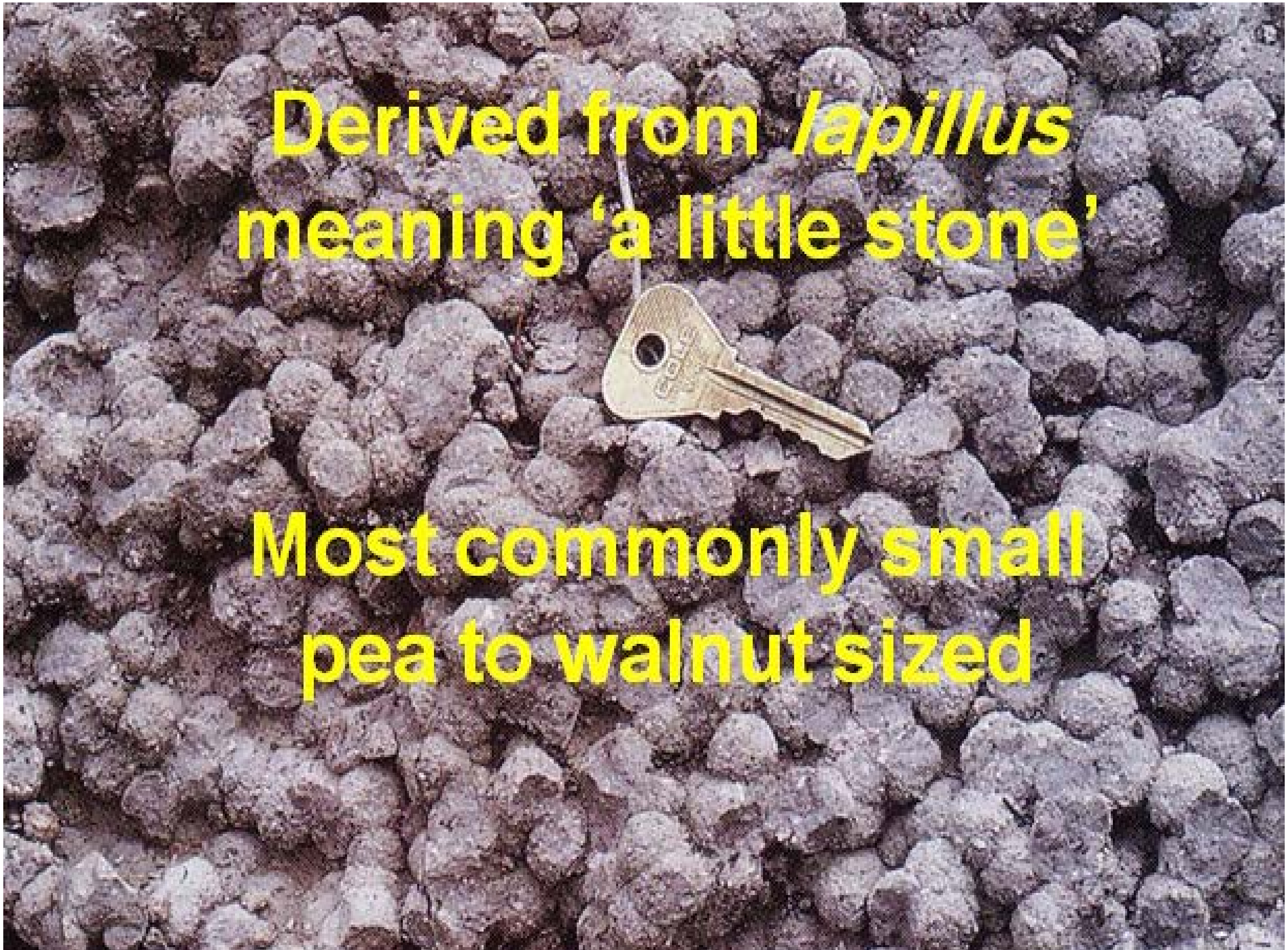
3.Lapili(Cinder): 2-64 mm

4.Blocks & bombs>64mm

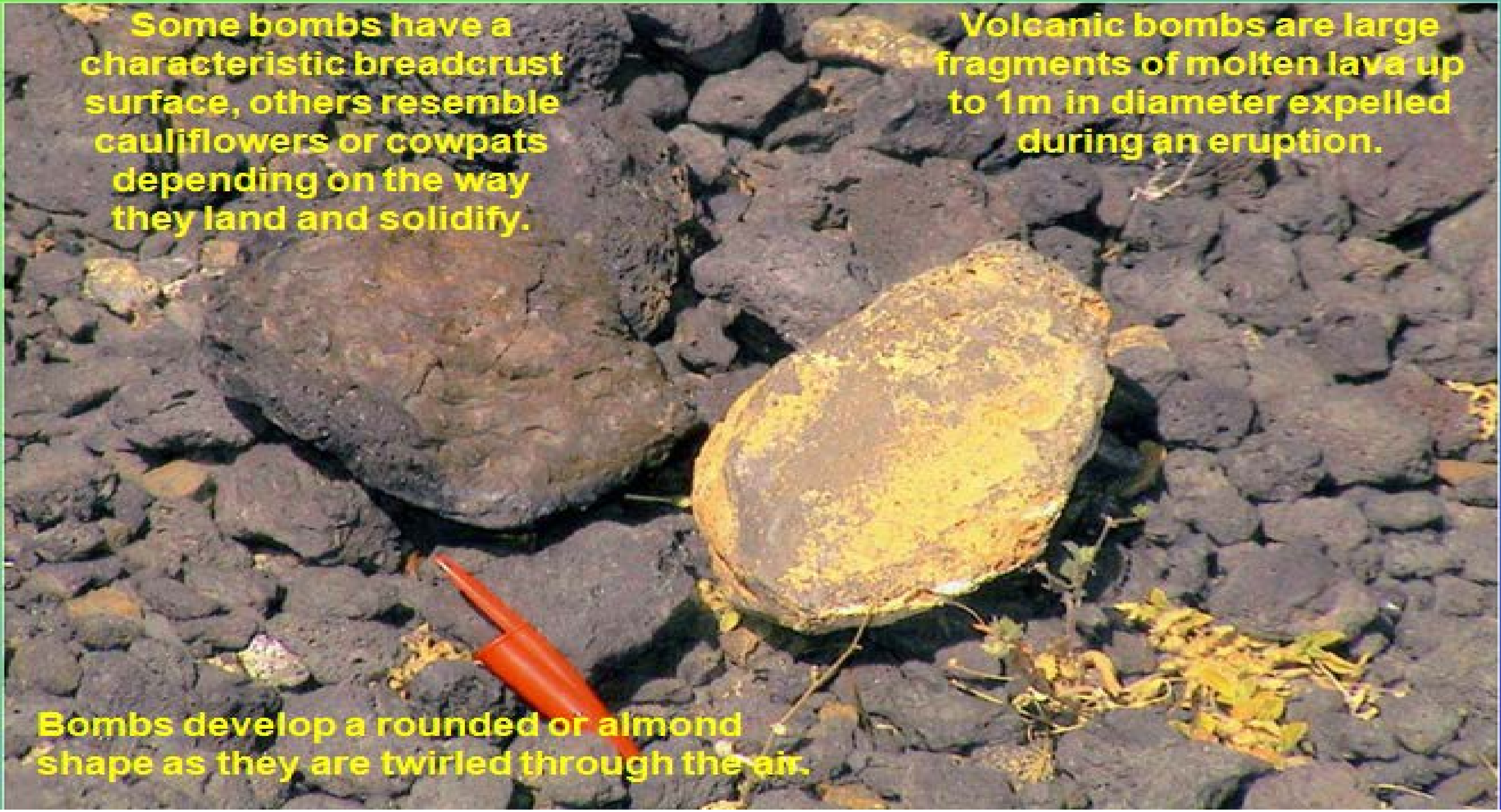
(Agglomerates)


Volcanic Ash – Unconsolidated
material <2mm in diameter


It is unwelded as the particles were cool by the time they had fallen 10-15km through the atmosphere back to earth
15m
This deposit covers more than 150 km2 of the Chimiche-Arico part of the island. It is thought to represent the collapse of a 10-15 km high plinian eruptive column


Derived from *lapillus* meaning 'a little stone'
Most commonly small pea to walnut sized

Volcanic Bombs



Igneous rocks structures

I. Extrusive (Volcanic) structures

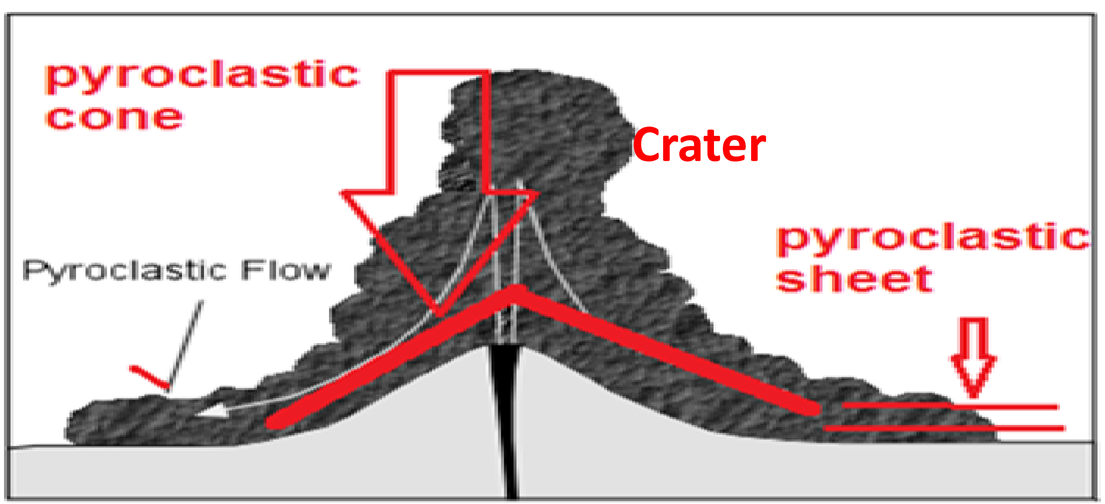
1. Volcanic Structures (Volcanoes)

A. Volcanic cone
B. Volcanic sheet
C. Volcanic crater

Volcanic cone (Volcano) Strucur:

- Pyroclastic sheet
- Pyroclastic cone

(pyroclastic material mostly rich silica high viscosity)



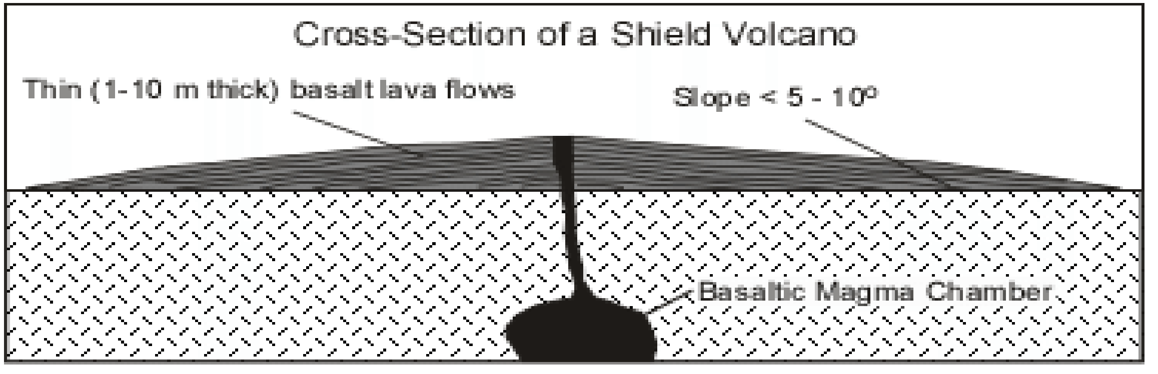
Shield Volcanoes

- A shield volcano is characterized by gentle upper slopes **(about 5º) and somewhat steeper lower slopes (about 10º).**
- Shield volcanoes are composed almost entirely of

  thin lava flows built up over a central vent.
- Most shields are formed by

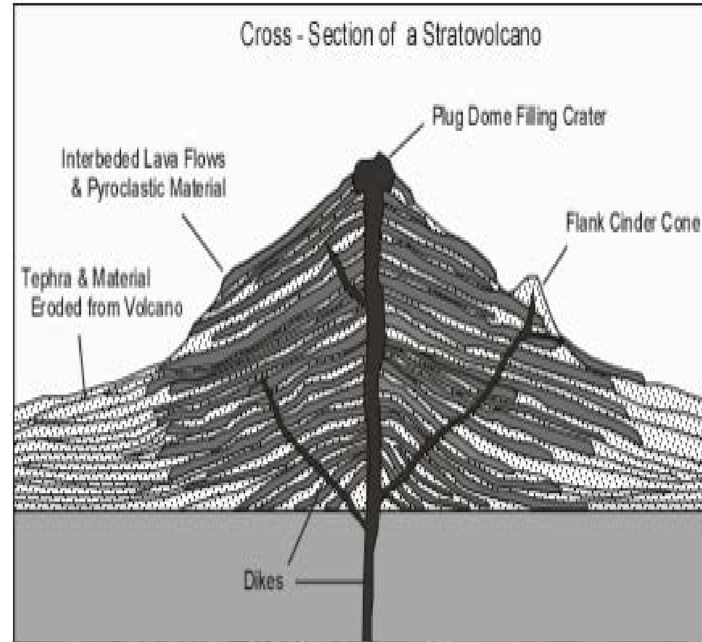
  low viscosity basaltic magma = basic

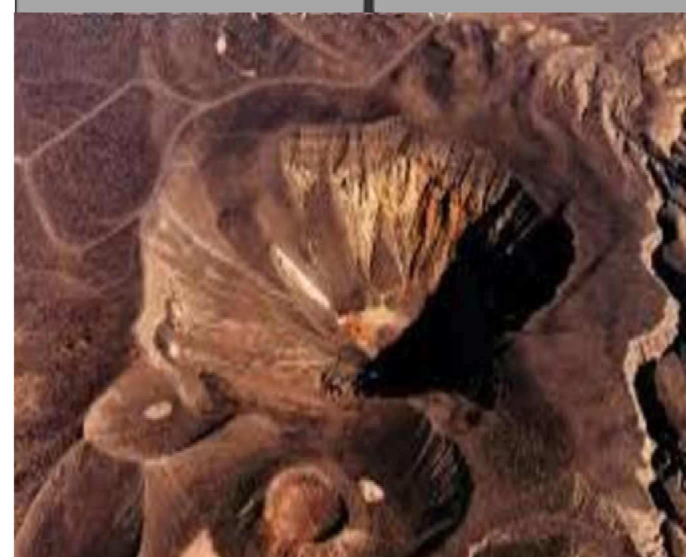
  that flows easily down slope away form a summit vent.
- **The low viscosity** of the magma allows the lava to travel down slope on a gentle slope,



B. Composite Volcanoes (Stratovolcanoes)

- Have **steeper slopes than shields**, with slopes of 6 - 10º
- Steep slope result from thick, short **viscous lava** flows that don't travel far from the vent.
- The **gentler slopes near the base** are due to accumulations of material eroded from the volcano and to the accumulation of **pyroclastic material**.
- Stratovolcanoes show inter-layering of **lava flows** and pyroclastic material, which is why they are sometimes called **composite volcanoes**. **Pyroclastic material** can make up over 50% of the volume of a stratovolcano.
- Lavas and pyroclastics are usually **andesitic** to **rhyolitic** in composition.





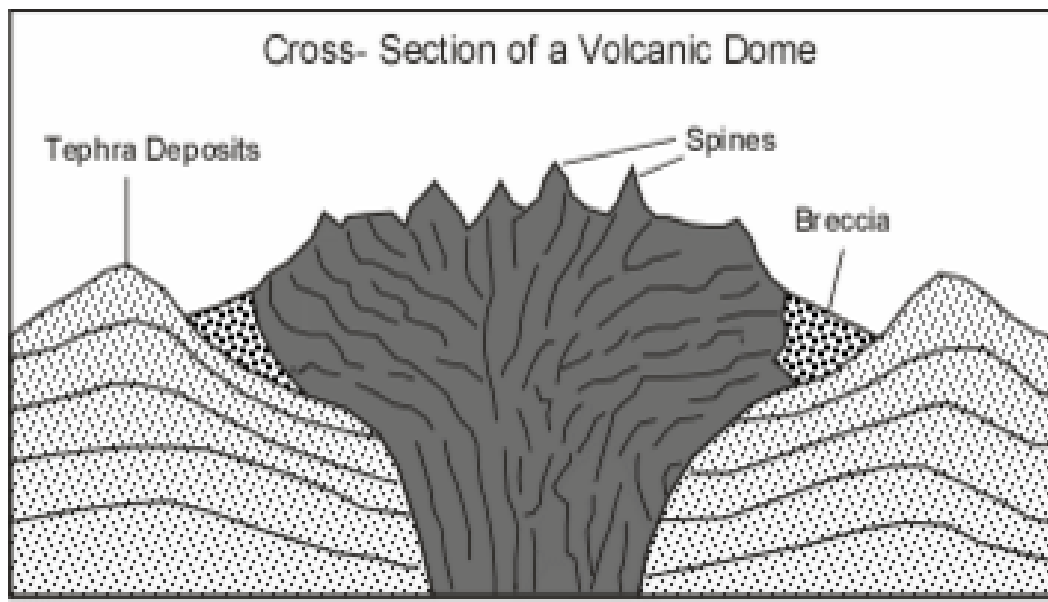
Lava domes

Lava Domes (also called **Volcanic Domes**)

- Volcanic Domes result from the extrusion of highly viscous, gas poor andesitic and rhyolitic lava. Since the viscosity is so high, the lava does not flow away from the vent, but instead piles up over the vent.

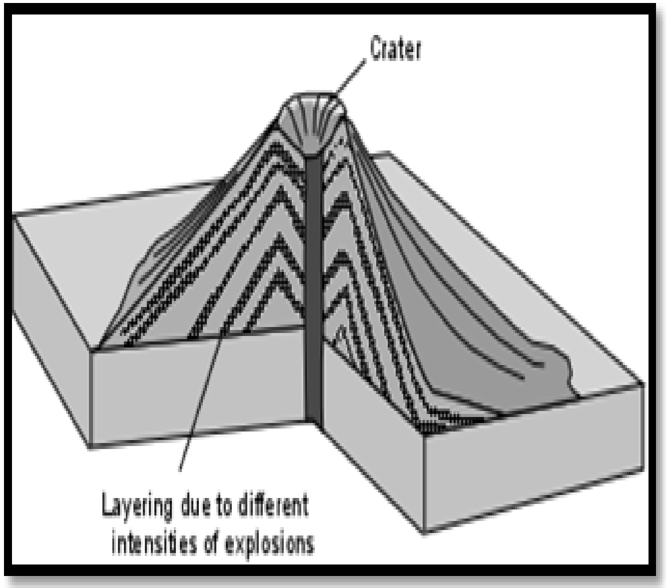
- Blocks of nearly solid lava break off the outer surface of the dome and roll done its flanks to form a breccia around the margins of domes.

- The surface of volcanic domes are generally very rough, with numerous spines that have been pushed up by the magma from below.

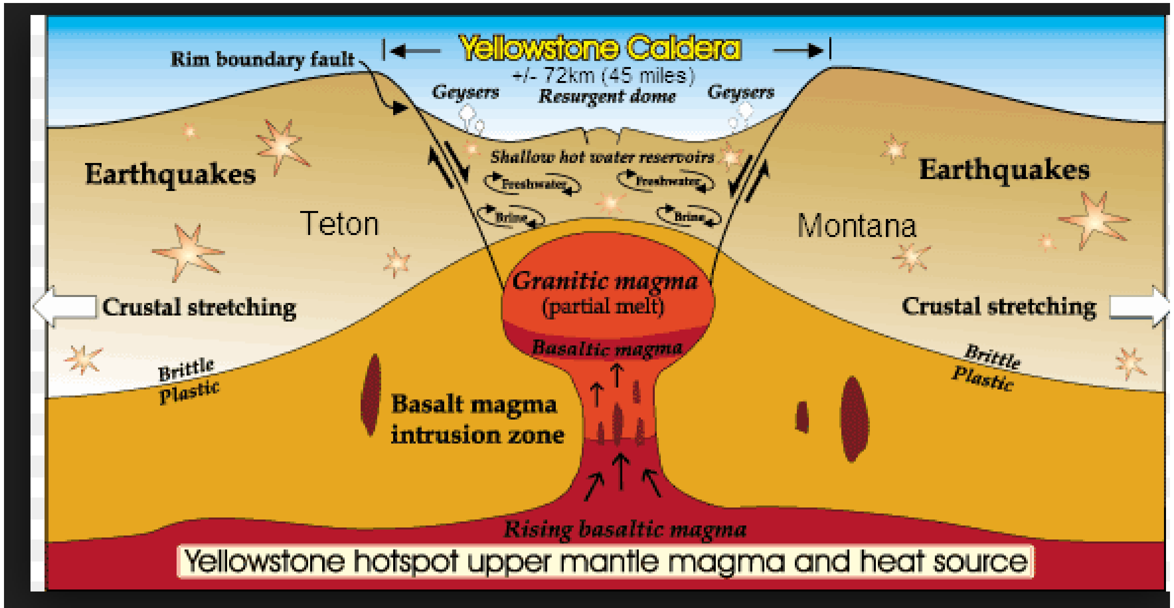


Crater & Caldera

- **Crater**
- are circular depressions, usually less than 1 km in diameter, that form as a result of explosions



- **Caldera**
- are much larger depressions, circular to elliptical in shape, with diameters ranging from 1 km to 50 km. Calderas form as a result of collapse of a volcanic structure.



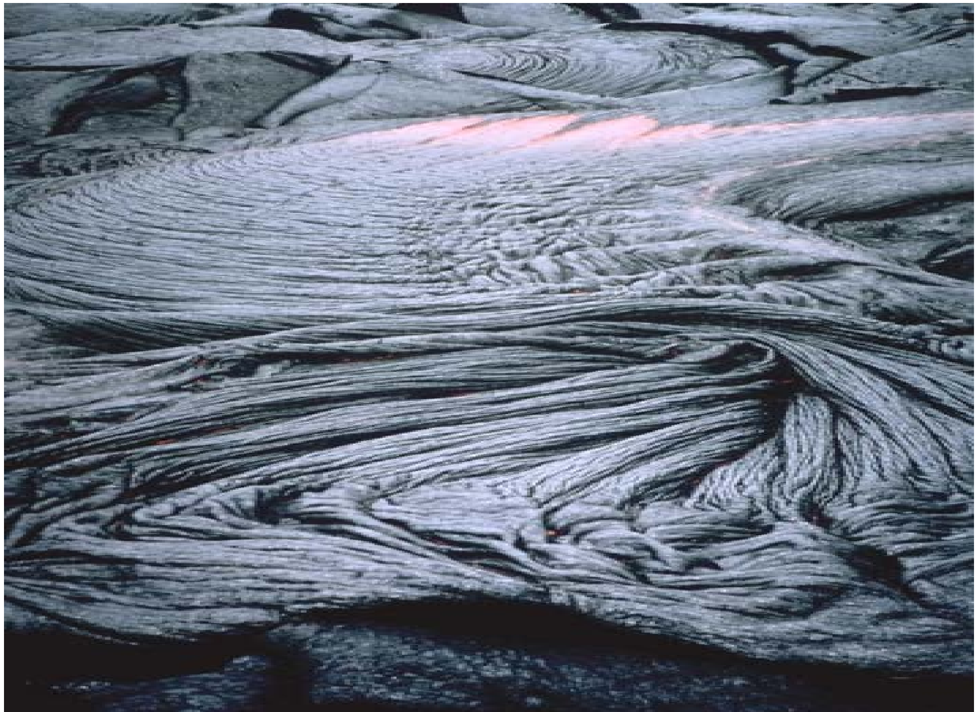
.Flow structures

.Bloky (ah ah) lava

is basaltic lavacharacterized by a **rough surface**

-Ropy (pahoehoe) lava

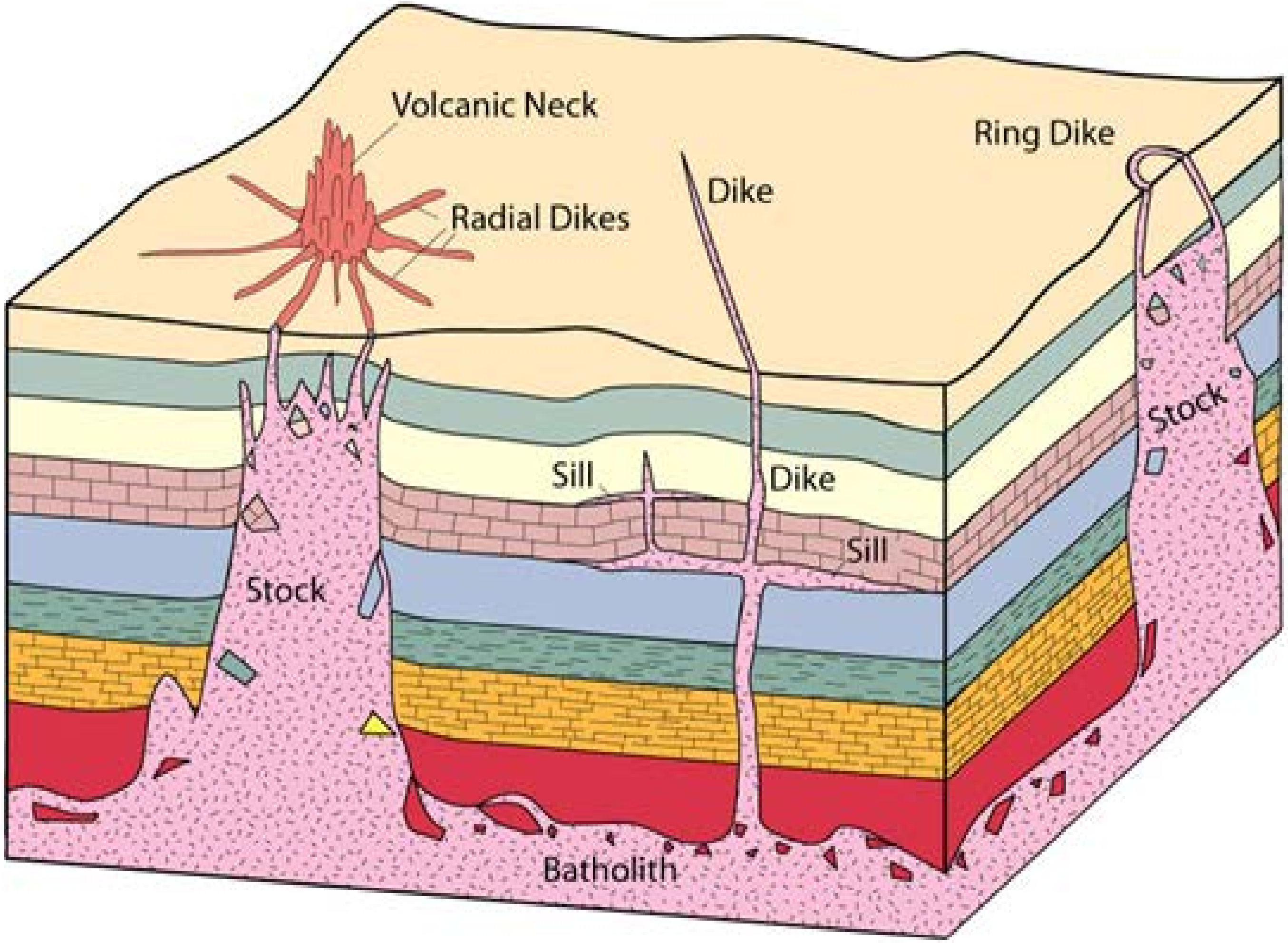
is basaltic lava that has a smooth, or ropy surface. These surface features



. Pillow lavas are lavas that contain pillow-shaped lava under water,

. Pillow lavas up to one meter in diameter.

II. Intrusive structures



A. Hypabyssal Intrusions

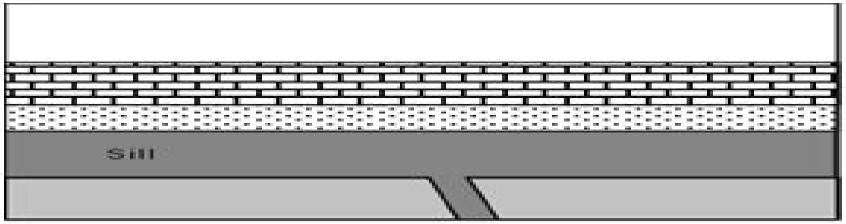
Intrusions that intrude rocks at shallow levels of the crust are termed hypabyssal intrusions.

*** Shallow generally refers to depths less than about 1 km.**

*** Hypabyssal intrusions always show sharp contact relations with the rocks that they intrude.**
Several types are found:

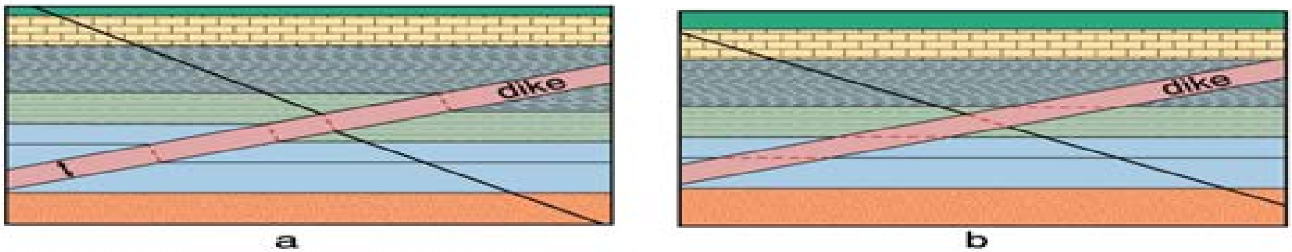
1. Sills are also small (<50 m thick) shallow intrusions that show a concordant relationship with the rocks that they intrude.

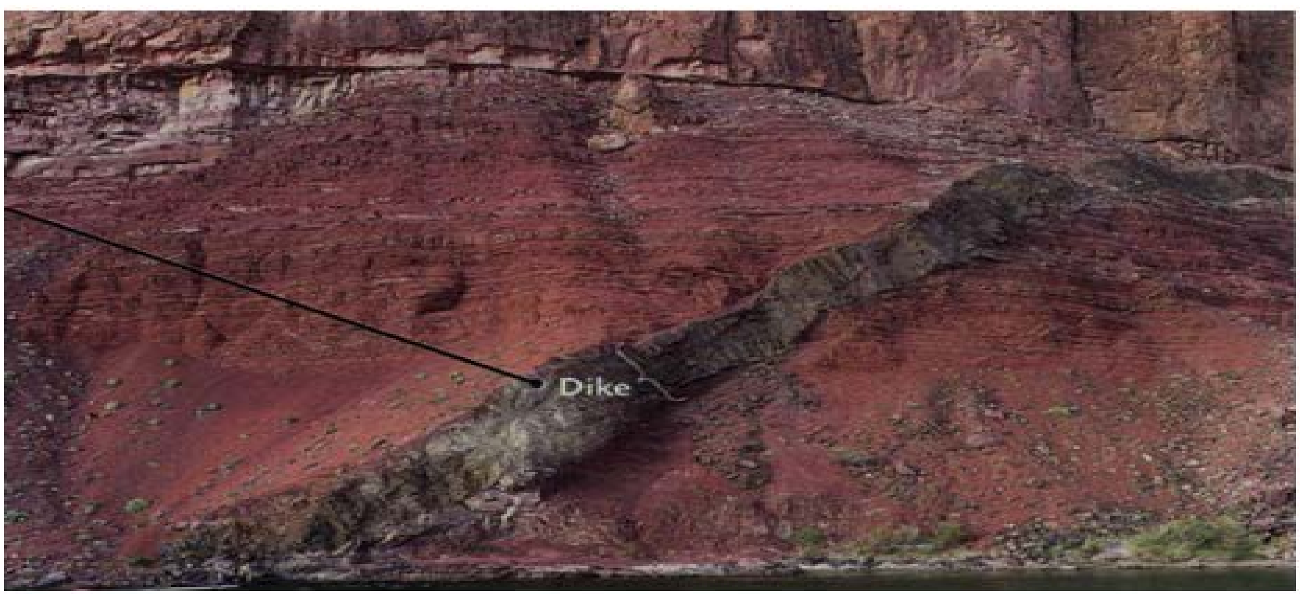
* Sills usually are fed by dikes, but these may not be exposed in the field.



2. Dikes are small (<20 m wide) shallow intrusions that show a discordant relationship to the rocks in which they intrude.

* Discordant means that they cut across preexisting structures.



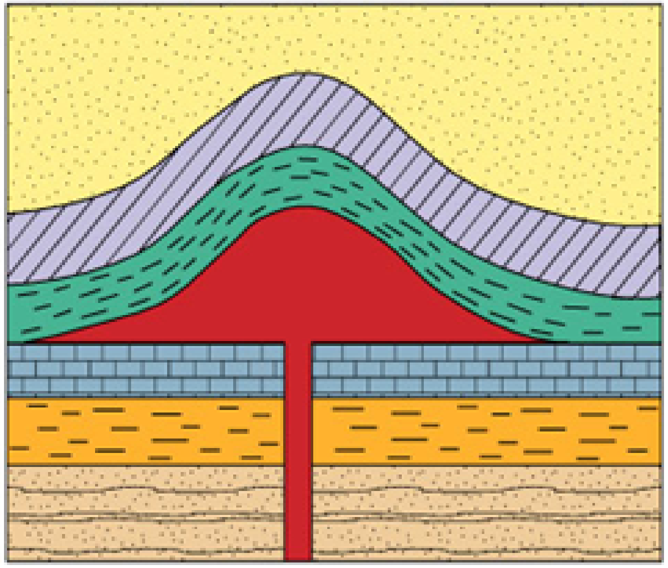


Types of dikes

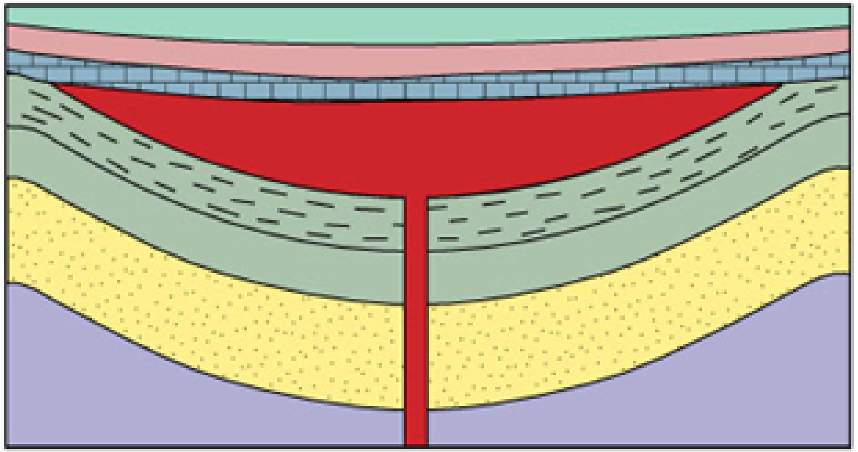
- **A- Laccoliths** are large concordant types of intrusions that result in uplift and folding of the preexisting rocks above the intrusion

B- Lopoliths are relatively small plutons that usually show a concave . This shape have resulted from the reduction in volume when magmas crystallize with the weight of the overlying rocks causing collapse of into the space once occupied by the magma when it had a larger volume as a liquid (mostly basic magma).

.

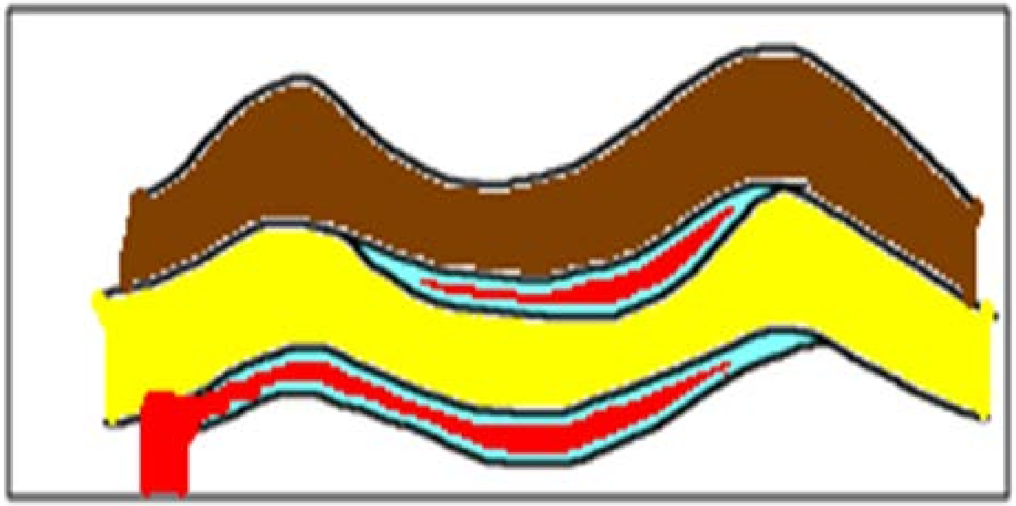


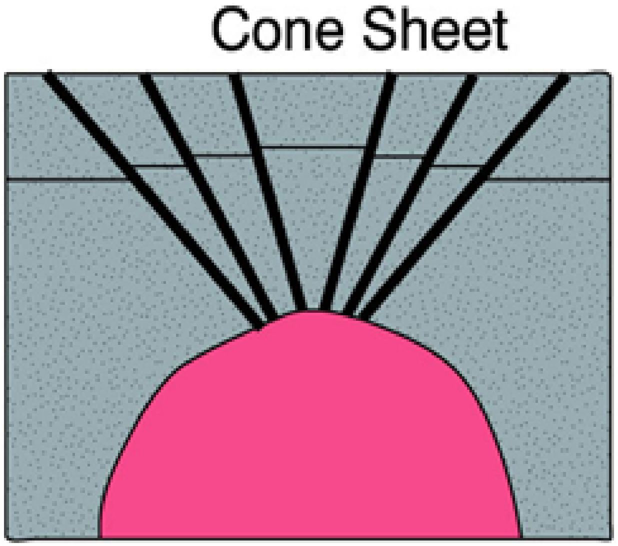
a

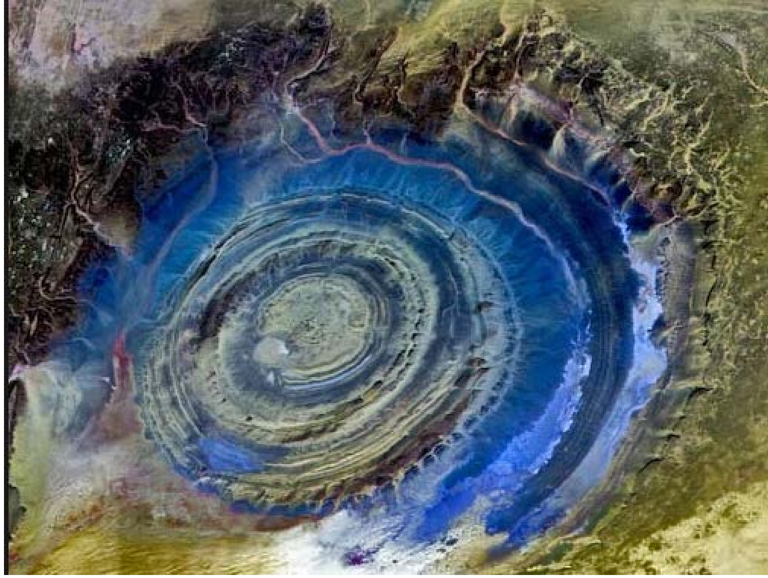


b

c. Phacoliths concordant bodies with lenticular or wavy shape , as a result from the folding of beds





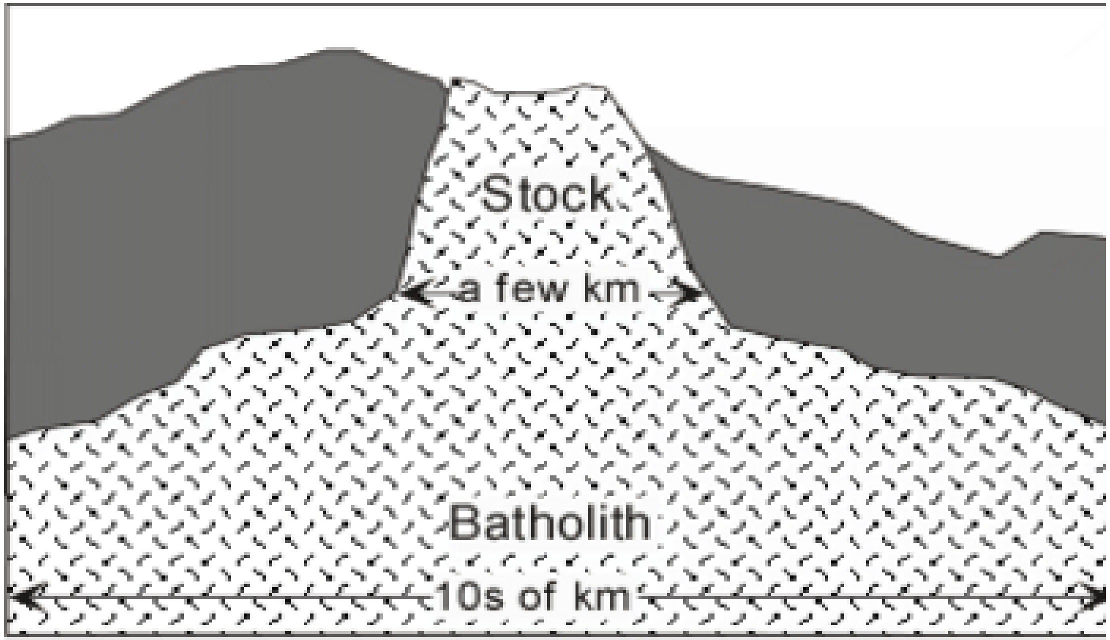


Cone sheet Upward pressure of a pluton lifts the roof as conical blocks in this cross section. Magma follows the fractures, producing cone

B. Plutons

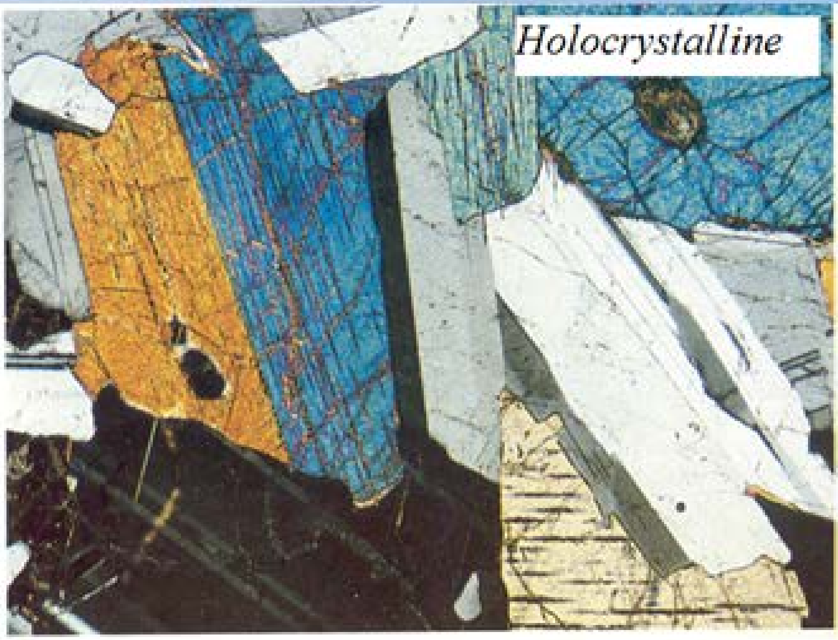
- **Batholiths** are very large intrusive bodies, usually so large that there bottoms are rarely exposed. Sometimes they are composed of several smaller intrusions.

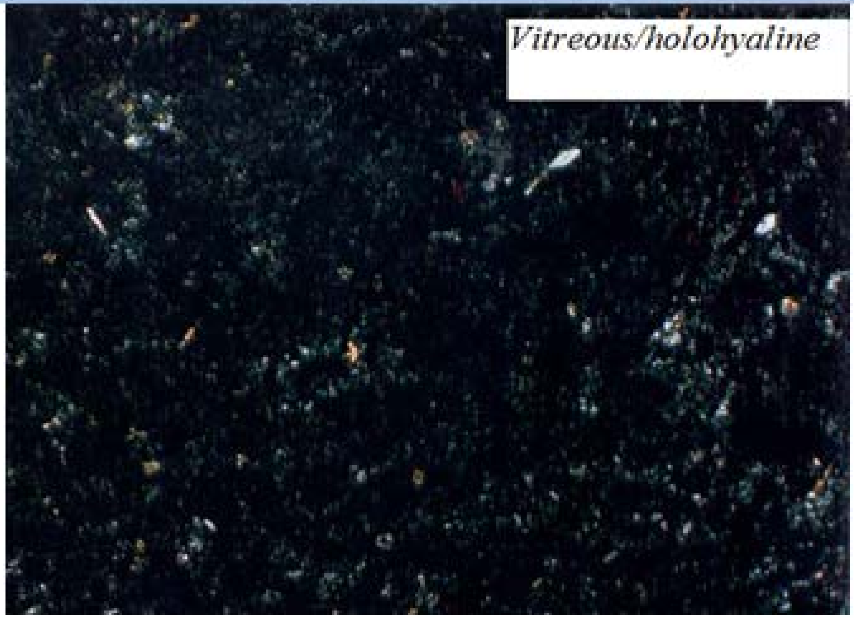
- **Stocks** are smaller bodies that are likely fed from deeper level batholiths. Stocks may have been feeders for volcanic eruptions, but because large amounts of erosion are required to expose a stock or batholith, the associated volcanic rocks are rarely exposed.

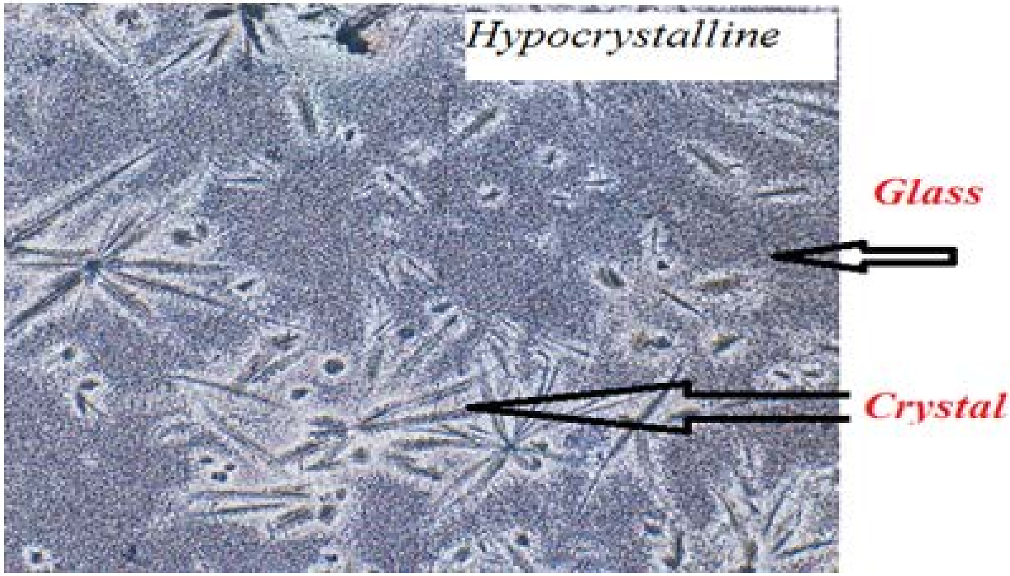


The texture of an igneous **rock** normally is **defined** by the size and form of its constituent mineral grains and by the spatial relationships of individual grains with one another and with groundmass .

- **TERMS USED WHEN DESCIBING TEXTURE OF IGNEOUS ROCKS**
- Below is a list of the words most commonly used to describe the textural features of igneous rocks. Some of the terms are illustrated with photomicrographs .
-
- **DEGREE OF CRYSTALLINITY**
- *Holocrystalline :*composed entirely of crystals.
- *Vitreous or holohyaline :*composed of glass.
- *Hypocrystalline :*composed of both crystals and glass.


Holocrystalline

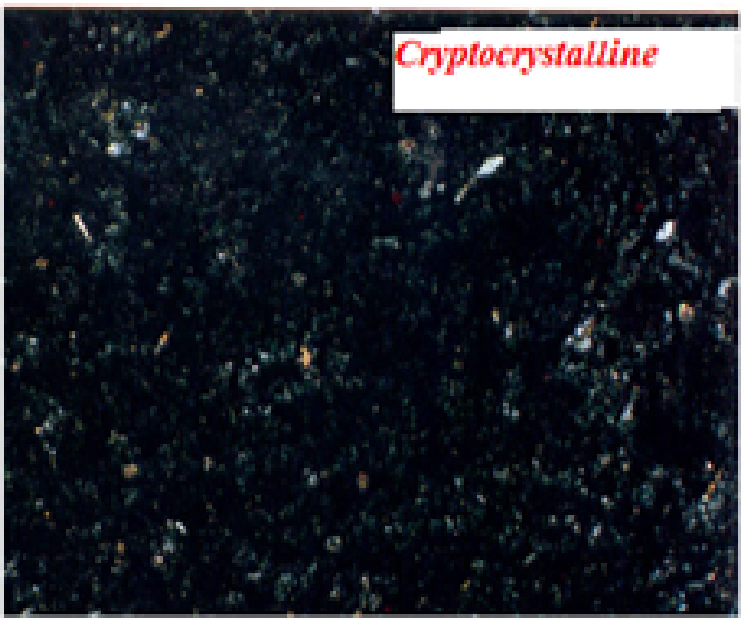

Vitreous/holohyaline


Hypocrystalline
Glass
Crystal

2- GRAINSIZE (Granultiy)

Microcrystalline crystals may be distinguished with aid of a microscope.

Cryptocrystalline mineral aggregate shown to be crystalline using scanning electron microscope or x-ray techniques but individual crystals not visible under the microscope. (like glass)

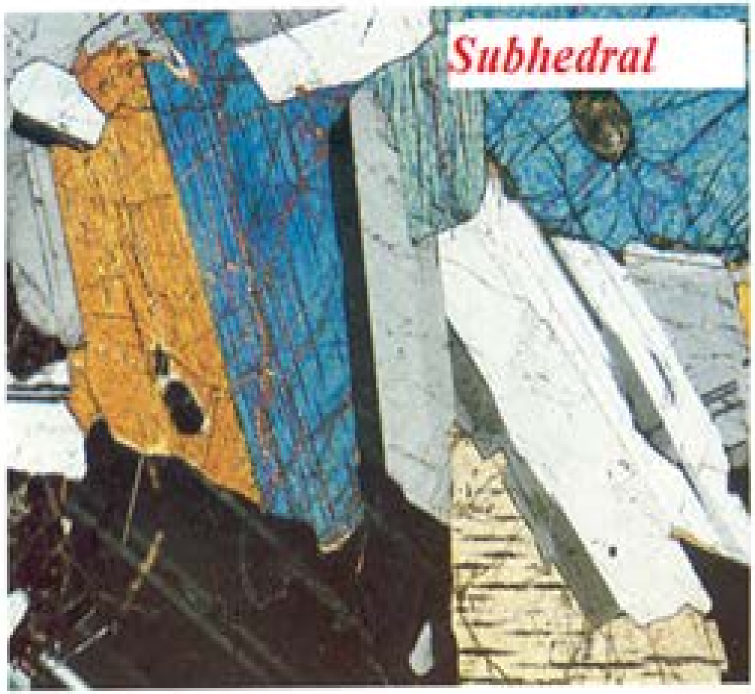


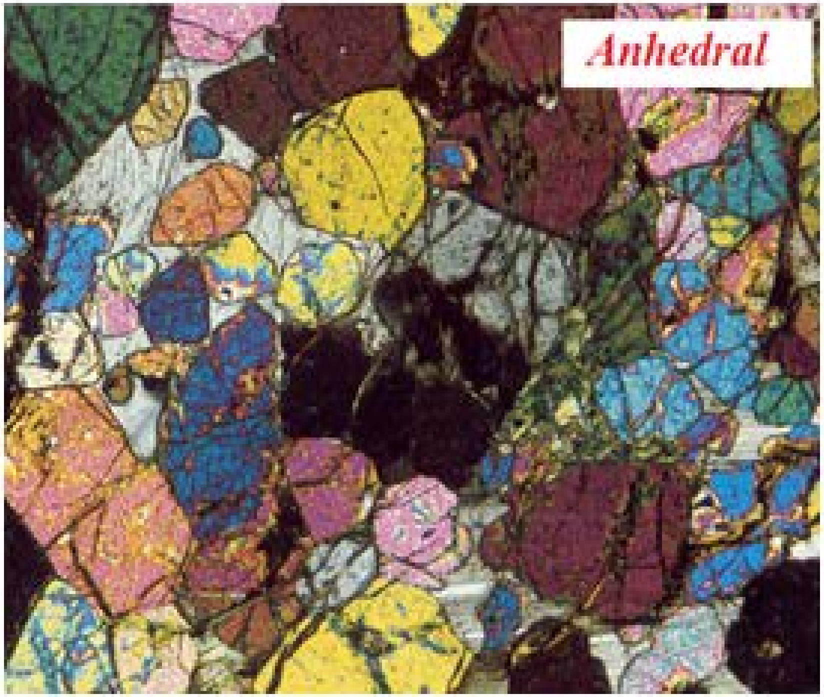
3. SHAPES OF CRYSTALS

Euhedral crystal is bounded by crystal faces.

Anhedral no crystal faces developed

Subhedral crystal faces partially developed.





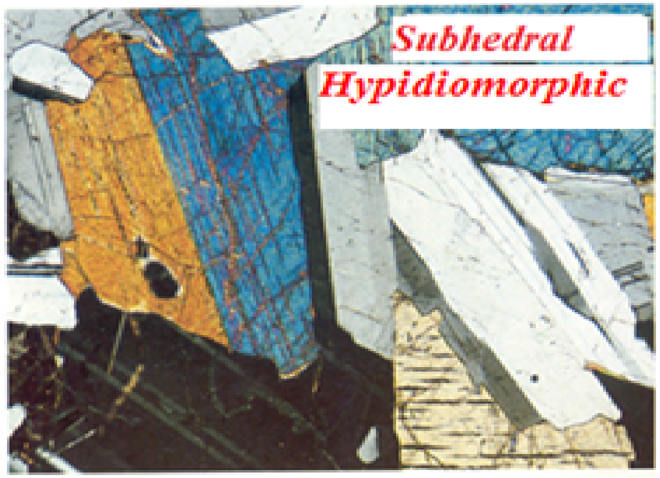
4. MUTUAL RELATIONS OF MINERALS (Relationship texture)

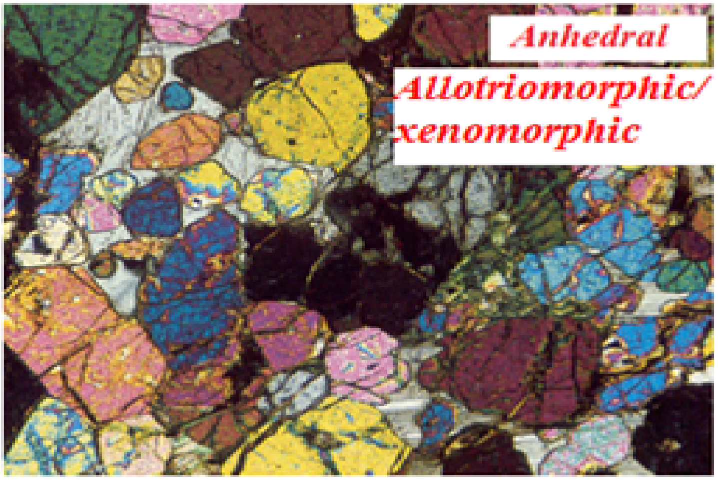
(a) Equigranular textures

Allotriomorphic/xenomorphic most crystals anhedral.

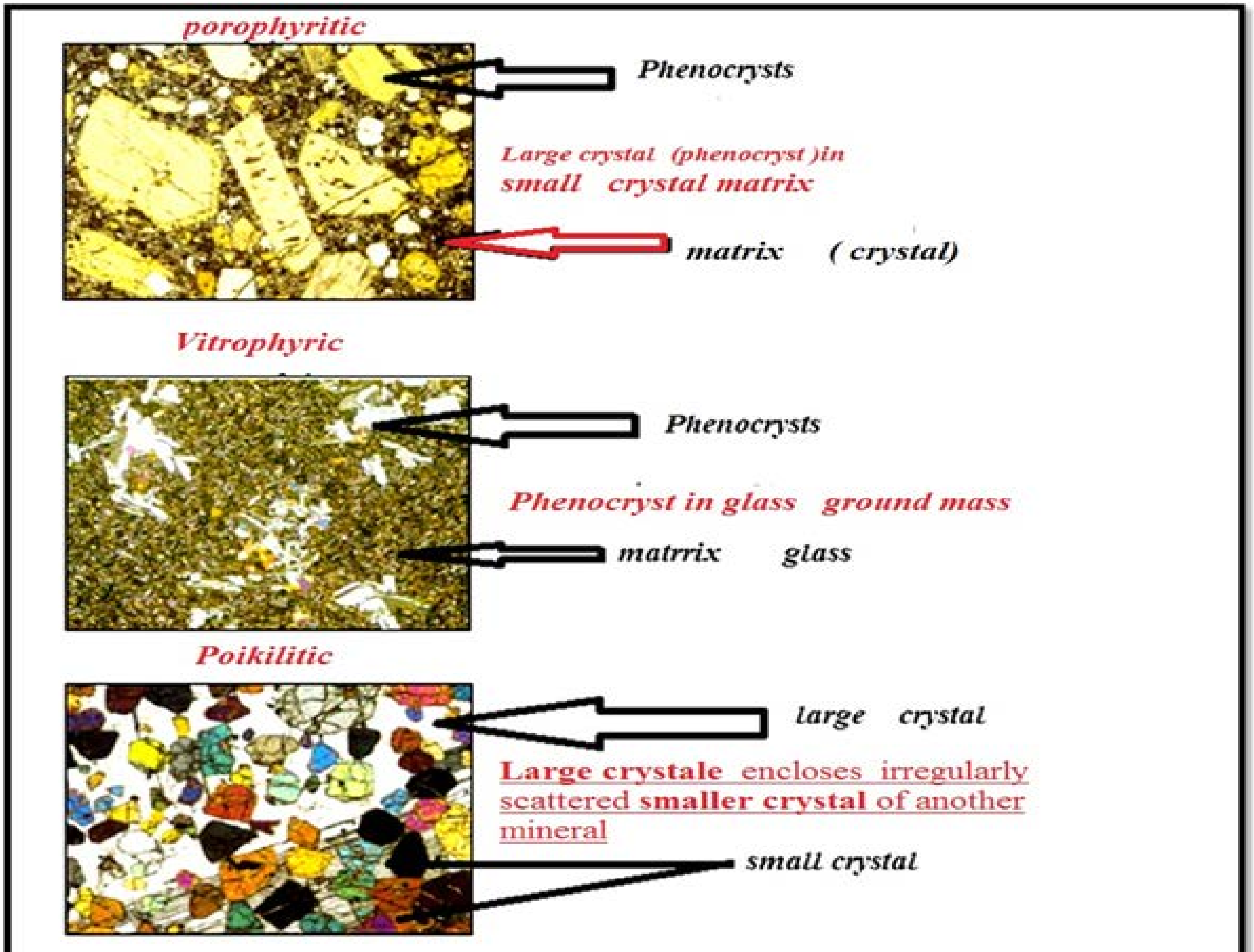
Hypidiomorphic most crystals subhedral.

Panidiomorphic most crystals euhedral.



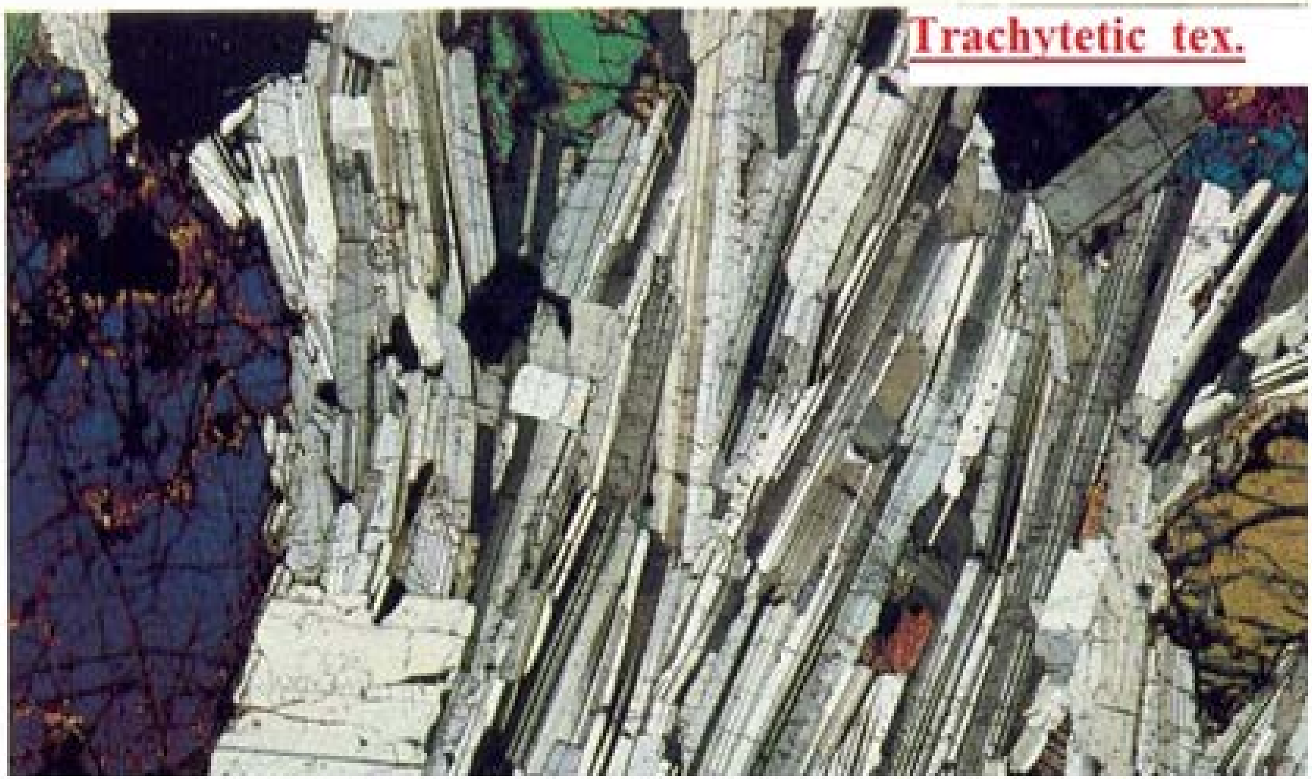


B- Inequegranular



Trachytic or directive tex.

Feldspars are aligned in sub parallel arrangement

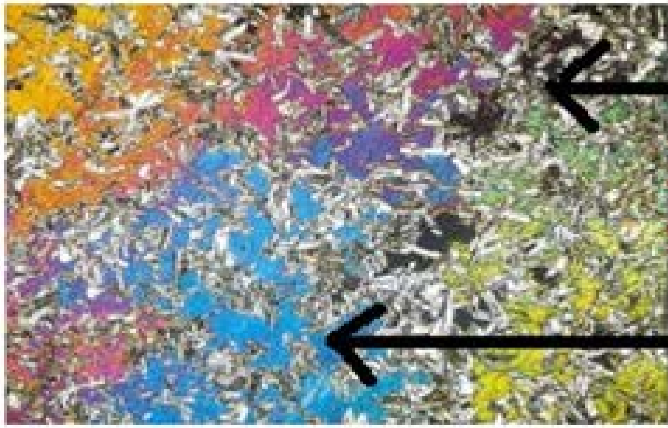


Ophitic

plagioclase

Several laths of **plagioclase are** enclosed in single pyroxen grain

Pyx. (Augite)



plagioclase

Several laths of **plagioclase are** enclosed in single pyroxen grain

Pyx. (Augite)

Sub ophitic : Augite encompassing the end of some plagioclase

Graphic tex.

Occurs in pegmatite rock consists of a very large crystal of alkali feldspar enclosing smaller crystals of quartz

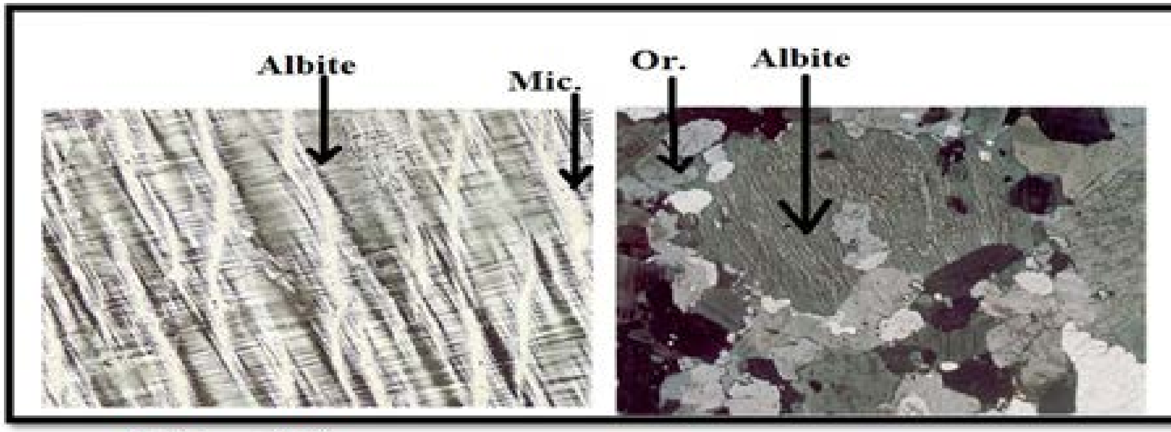
Zoned

Many minerals such as plagioclase ,clinopyroxen,and garnet exhibit zoning (a layered character resulting from changes in composition from the core to the rim of mineral

Corona

Is a rim radiating minerals surrounding a core mineral.

Perthite : Growth albite in orthoclase or microcline



Antiperthite

Growth orthoclase in albite

Movement of magma

Magmas can move upward in two main ways.

1- **Fluid flowing in cracks.**

This requires that the country rock be brittle to sustain cracks.

2- **Where a fluid magma encounters plastic rocks**

A- The magma can rise only if it is of lower density.

B- If it is of higher density, it gets stopped below the plastic rocks (**underplating**).

Heating of Country Rock

- **Heating** As hot magmas passes through colder country rock, the magma cools and the country rock heats. This can result in

  1- contact metamorphism

  2- Melting of the country rock or making it plastic .

  3-The magma might develop chilled margins from the rapid cooling at the edges.

PLATE TECTONICS

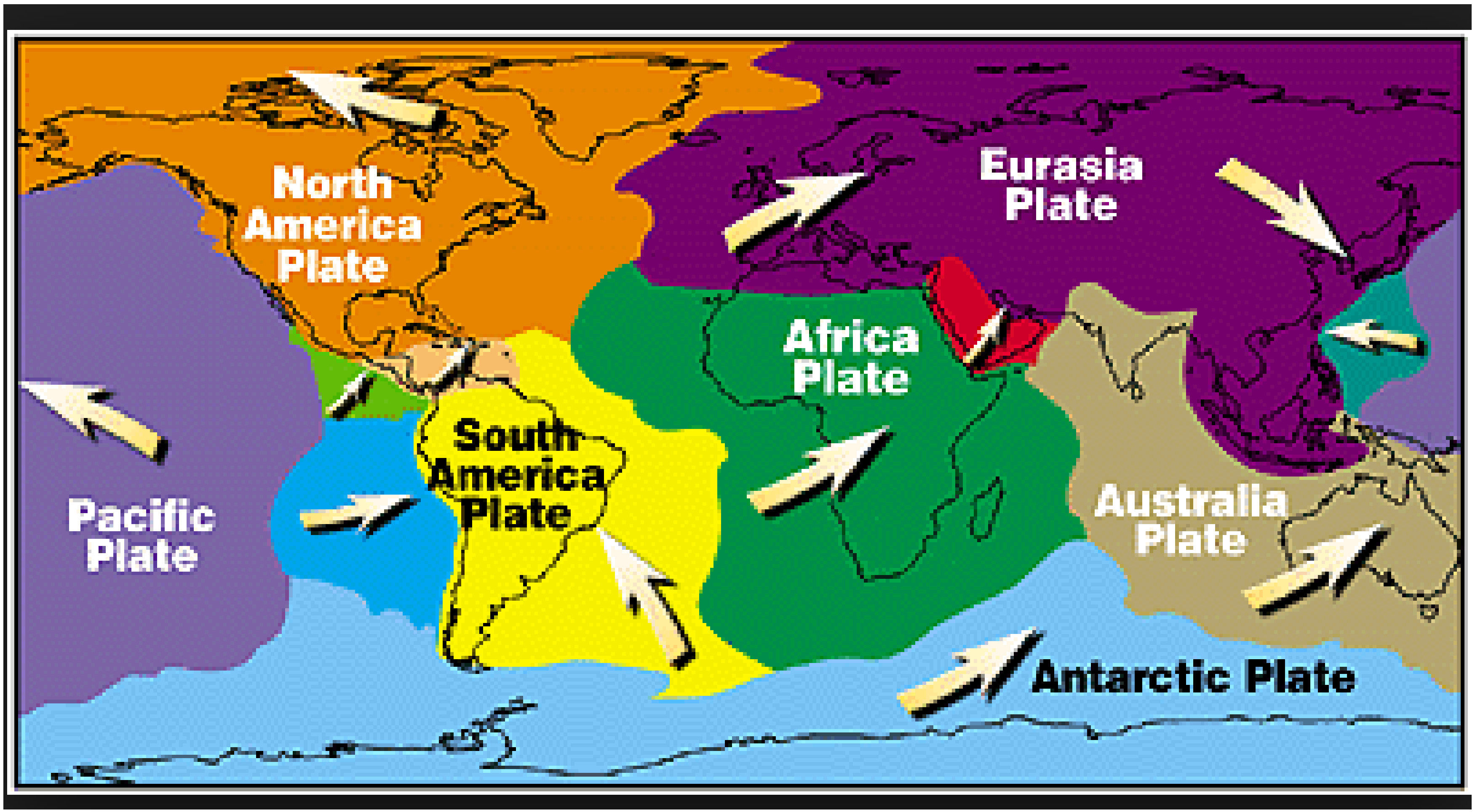
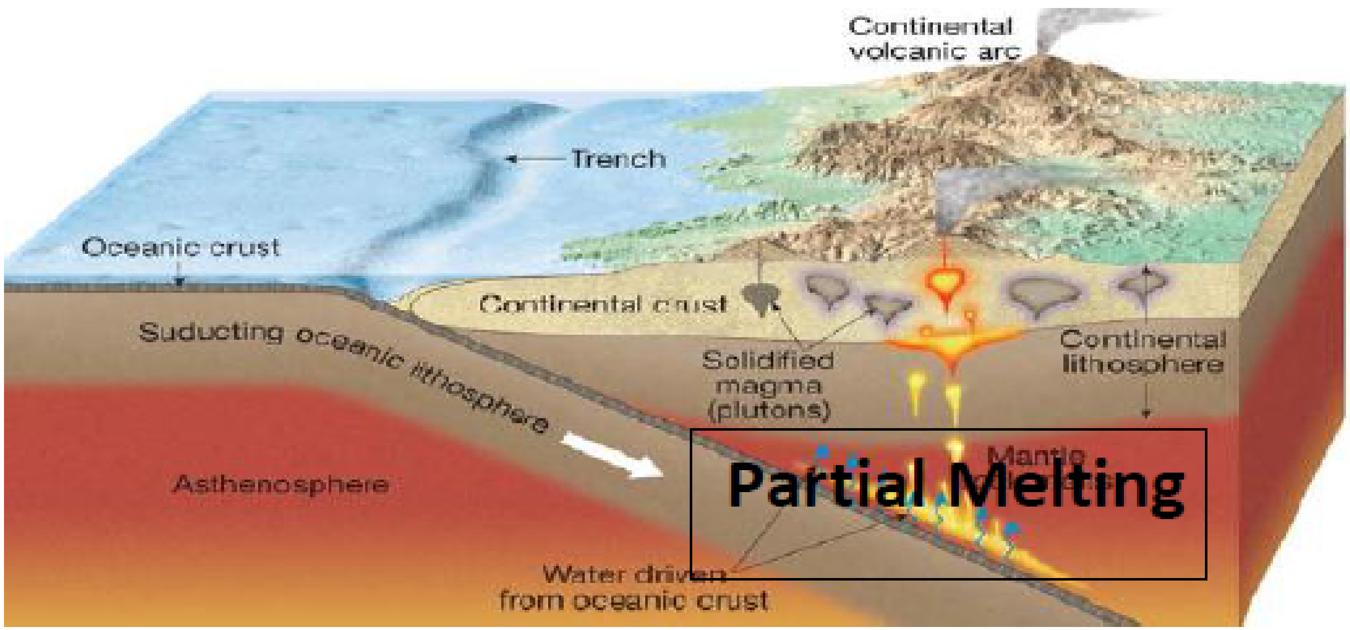


Plate Tectonics and the Origin of Igneous Rocks

- Plate tectonics explains igneous activity fairly well. Most igneous intrusions are associated with plate boundaries. There is also igneous activity associated with hot-spots.

Partial Melting is a refining process.

Certain elements go into the melt, others stay in the restite. Crystallization can be a refining process.



Typical site of magmas

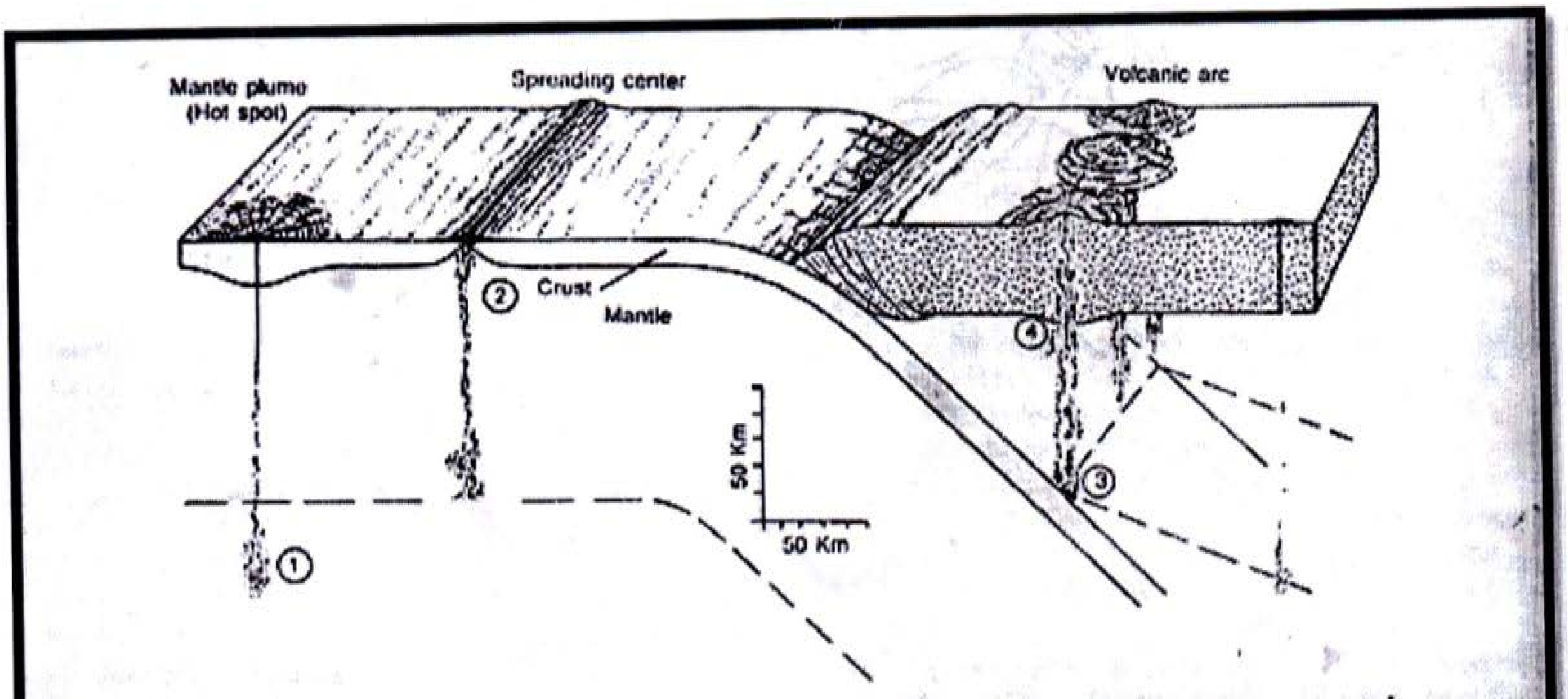
1- Mantle hot spot (plume) source.

2- Site in mantle below a spreading center

3- Site where the top of subduction lithosphere intersects the base of the over lying lithosphere

4- Site at the base of the crust **In collision plates.**

Note: the dish line is the base of lithosphere



Divergent (Basalt)

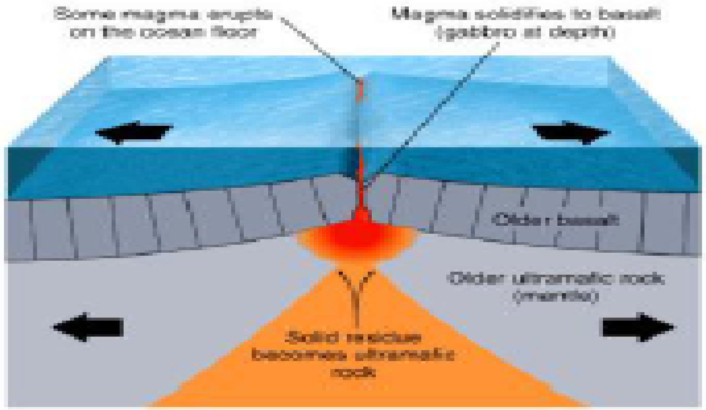
Oceanic basalts are derived by partial melting of mantle material, and occur

1- Extensively at mid-ocean ridges

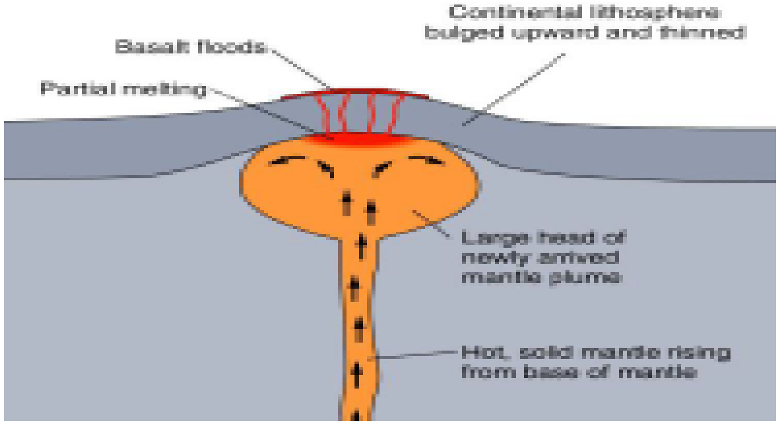
2- some oceanic hotspots.

3- Most volcanic activity occurs as pillow basalts at divergent plate boundaries.

4- Early in the rifting apart of a continent, bi-modal volcanism (rhyolites and basalts) occurs.



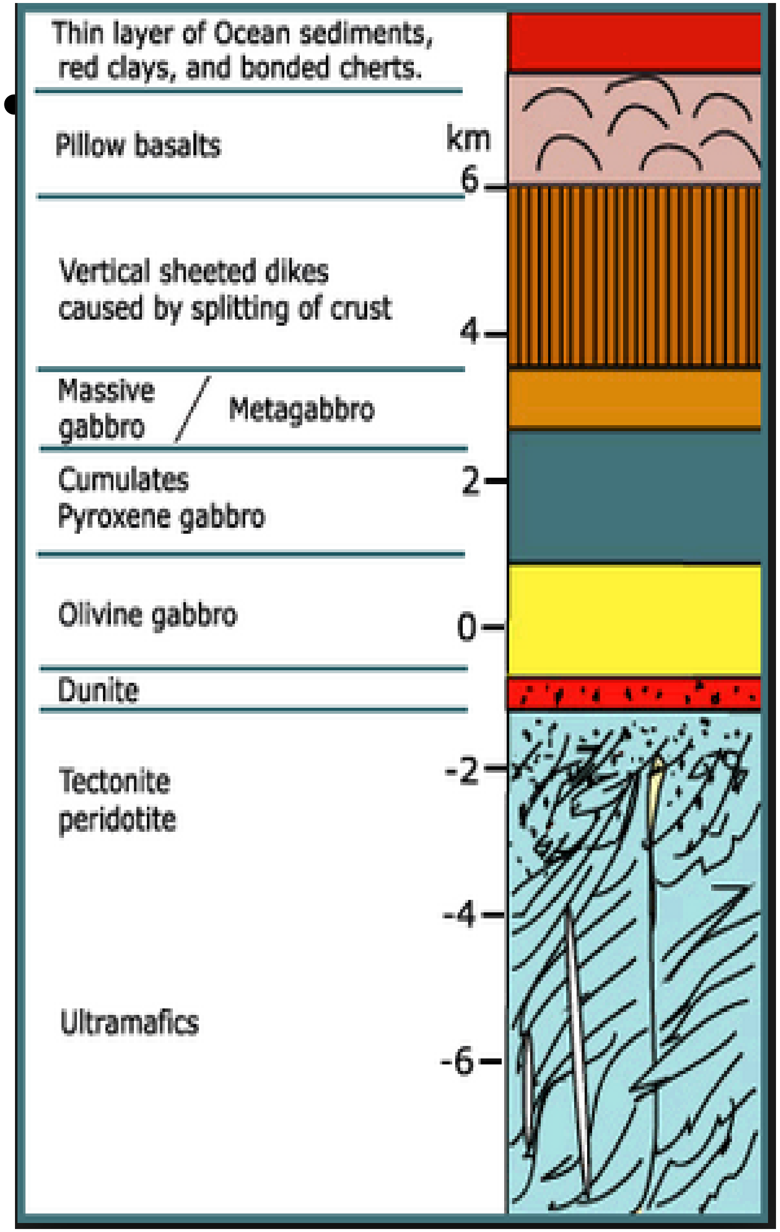
Mid-Oceanic ridge MOR



Rifting apart of a continent

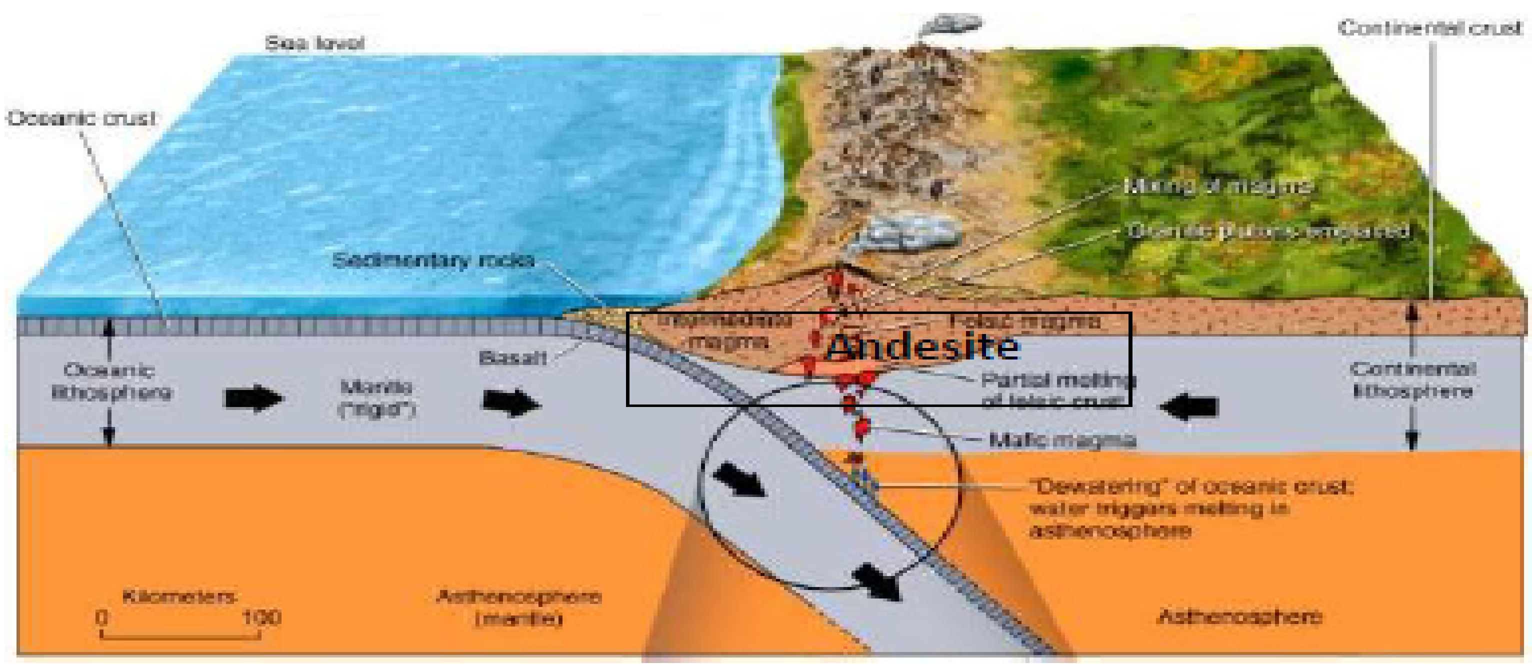
The Ophiolite

Ophiolite complexes or ophiolites (snake stones) are uplifted or emplaced sections of oceanic crust rocks and subjacent upper mantle that become exposed within rocks of the continental crustal. The age of ophiolite formation is often quite close to the age of their emplacement into the continental crust).The typical rock succession of ophiolites shown in this figure.



Subduction (Andesite)

- At ocean-subducting convergent boundaries, wet basalt is heated as it subducts, resulting in partial melting of basalt to produce andesite.
- **Subduction-zone andesites** are derived by water- and pressure-induced partial melting of basalt and sediments that are being subducted. There may also be partial melting of mantle peridotite leading to basaltic magma.
- The constancy of composition of andesite in collision zones suggests it's a partial melt, rather than a mixing Mgma.



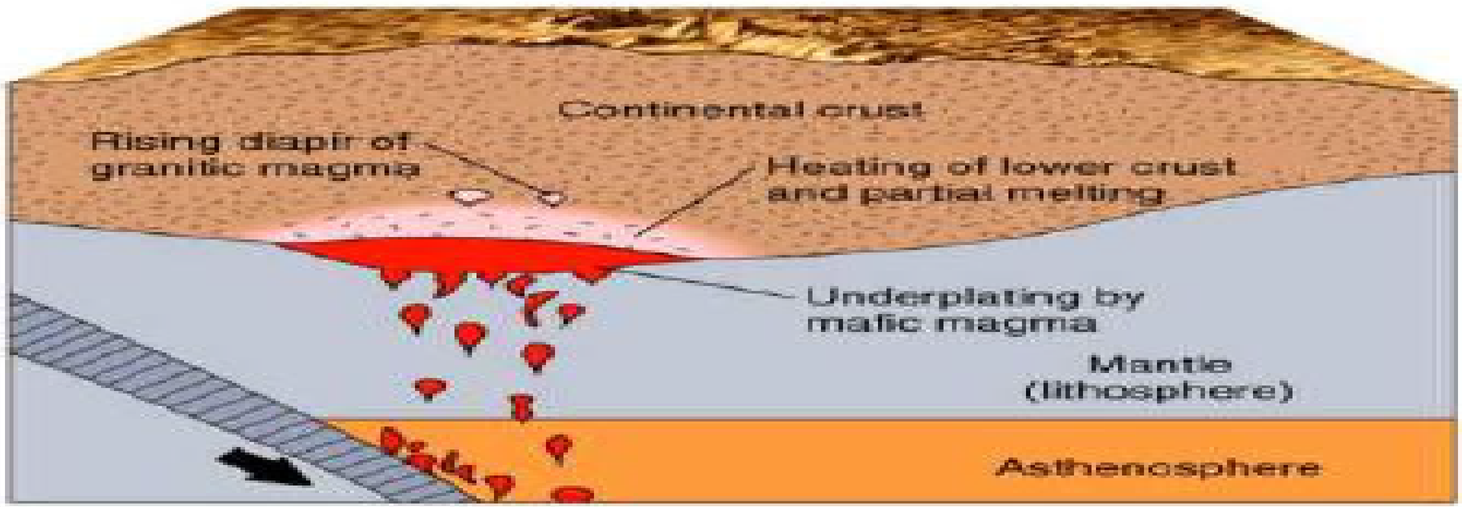
Collision Granite

- At continent-continent convergent boundaries (collision zones), wet andesitic, granodioritic, and sediments and metamorphic rocks are compressed and yield granitic magma which freezes as it ascends.
- Granitic magmas appear to have several sources.

  1- Most are due to compressive melting of water-rich sediments, as occurs in deep burial or continent-continent collisions.

  2- Another is secondary melting, due to underplating by basaltic or andesitic magmas and heat transfer.

  3-Andesitic magmas might incorporate sediments and move towards a granitic composition. Continent-continent collisions mainly result in intrusive granites.

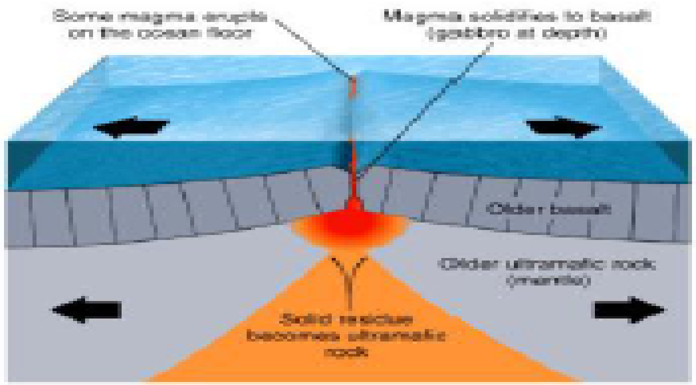


Hot Spots

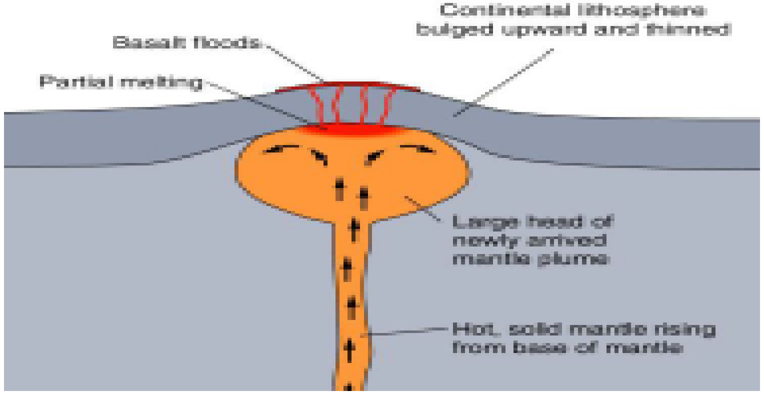
Hot spots are tracks of volcanism (age increases away from current activity) that are not associated with plate boundaries (and earthquakes and structural deformation). The Hawaiian islands are one in an ocean .

The hot spots are where a plume of hot material has welled up from the mantle (sort of like a thunderhead).

1- Under oceans, they almost always erupt as flood basalts or shield volcanoes.
2- Under continents, they might erupt as flood basalts or shield volcanoes, or they might heat the continental material enough to make it plastic and block further mafic eruptions, but trigger secondary underplating granites and rhyolites.

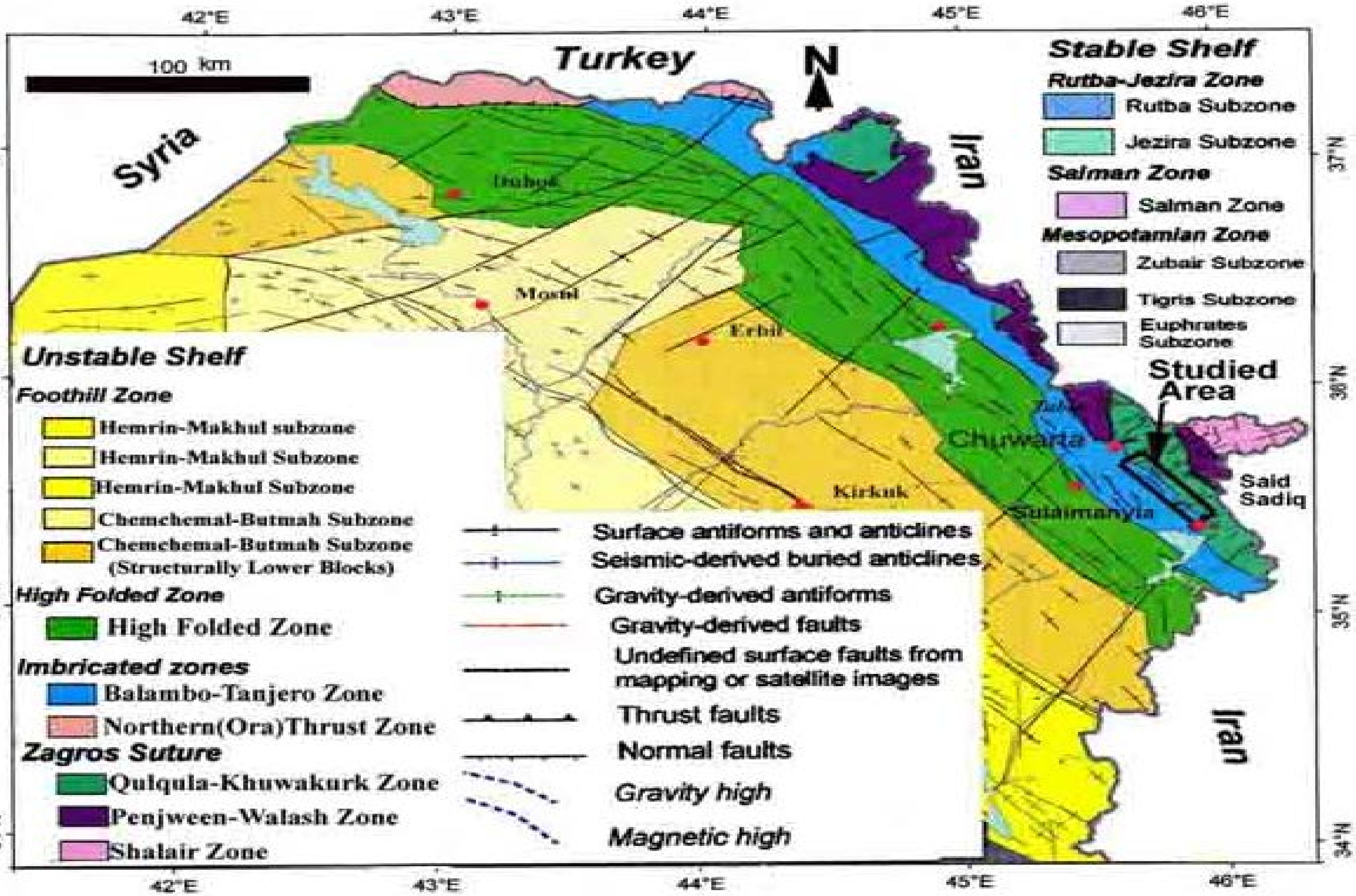


Mid-Oceanic ridge MOR



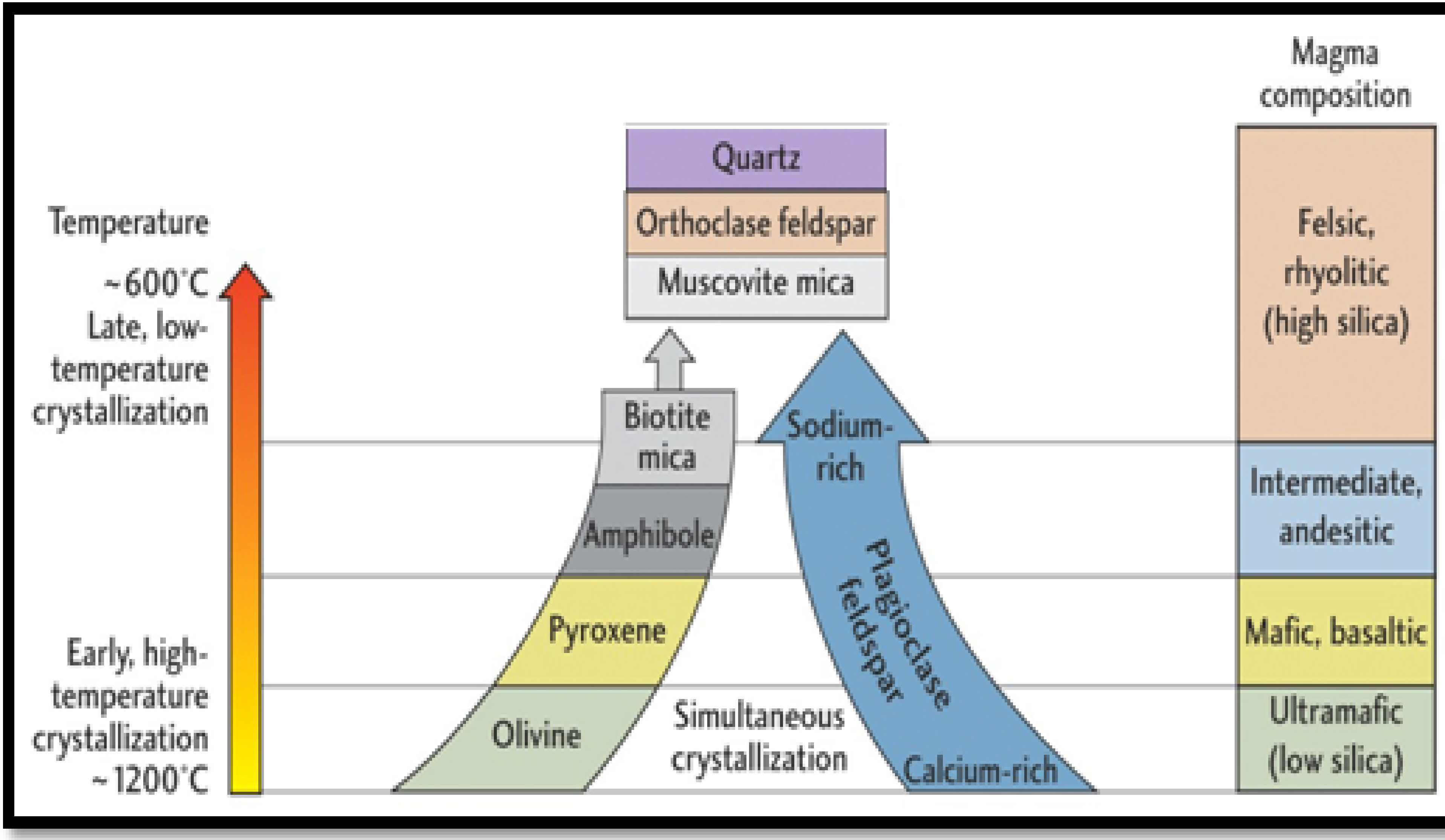
Rifting apart of a continent

IGNEOUS ROCKS IN IRAQ



Crystallization and Evolution of magma

- **Crystallization of Magma (Bowens' reaction series)**



Magma Formation

- **Partial melting and magma formation**
- partial melting is Incomplete melting of rocks forming basaltic magmas.

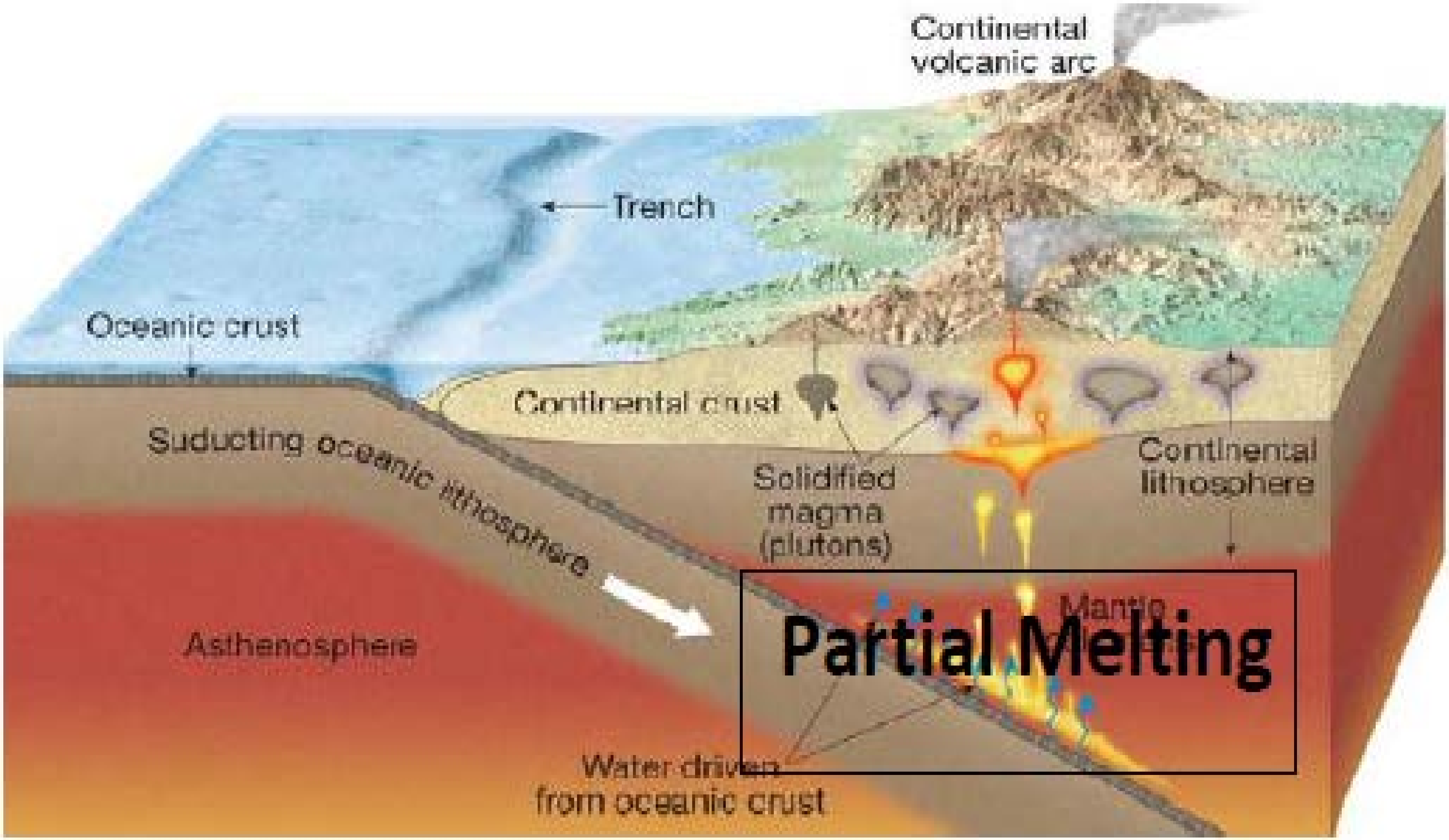
– Most magmas originate from the partial melting of mantle rocks at oceanic ridges.

– Large flows of basaltic magma are common at Earth's surface

- A.Partial melting and formed magma

 produce andesitic magmas by interaction of basaltic magmas and more silica-rich rocks in the crust

- Or may also devolve by magmatic differentiation



Continental volcanic arc
Trench
Oceanic crust
Continental crust
Suducting oceanic lithosphere
Solidified magma (plutons)
Continental lithosphere
Asthenosphere
Partial Melting
Water driven from oceanic crust

b. Partial melting and formed magma

form granitic magmas most likely form as the end product of crystallization of andesitic magma.

– Granitic magmas are more viscous than other magmas—tend to lose their mobility before reaching the surface.

– Produce large plutonic structures

Evolution of Magmas

-Processes responsible for changing a magma's composition

1. Mixing of magmas
2. Magmatic differentiation

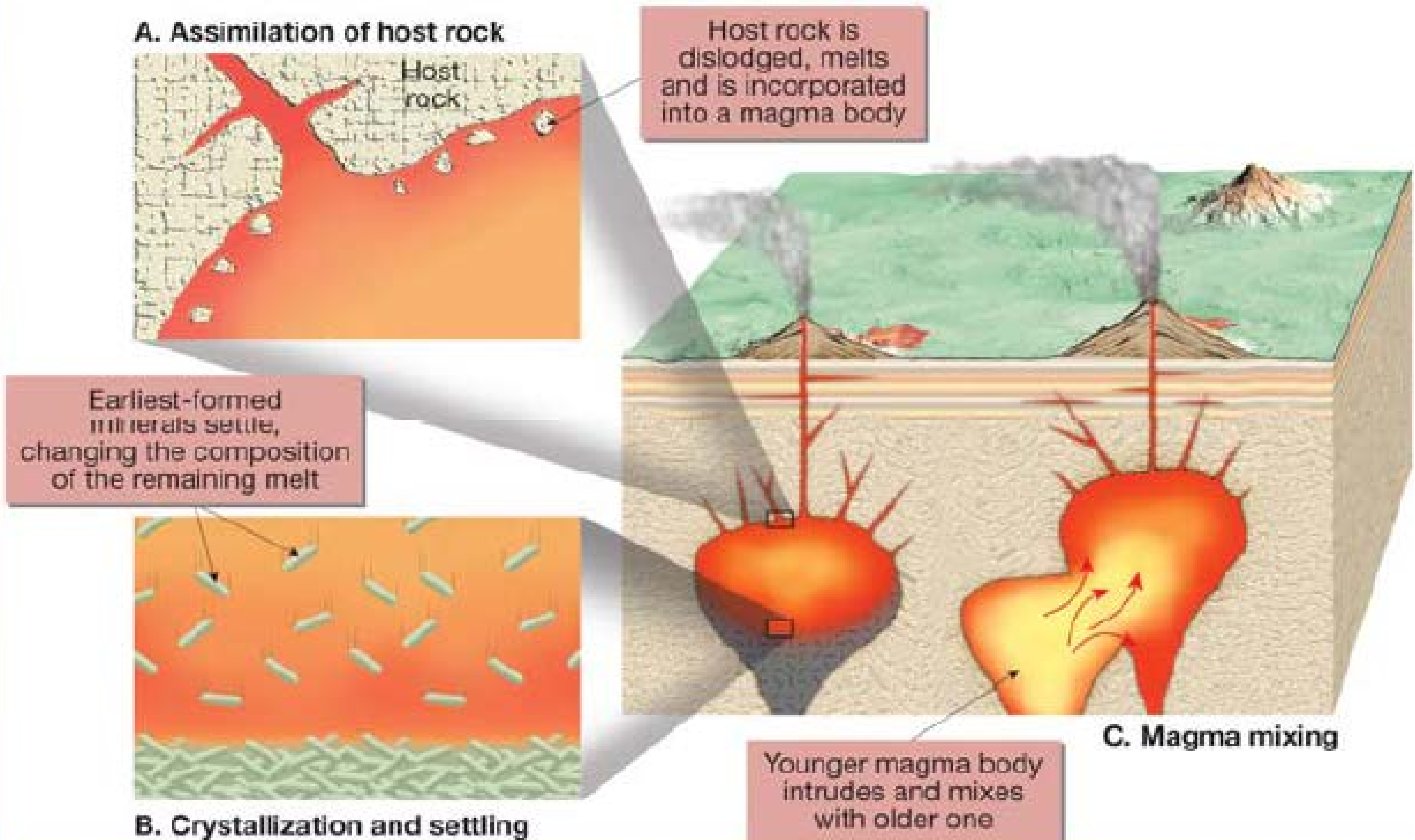
– Separation of a melt from earlier formed

Crystals (Bowen' reaction series)

3. Assimilation or Contamination

– Changing a magma's composition by incorporating surrounding rock bodies into a magma

Assimilation, Magma Mixing, and Magmatic Differentiation



Evolution of Magmas

- Processes responsible for changing a magma's composition

1• **Magma mixing**

– Two chemically distinct magmas may produce a composition quite different from either original magma

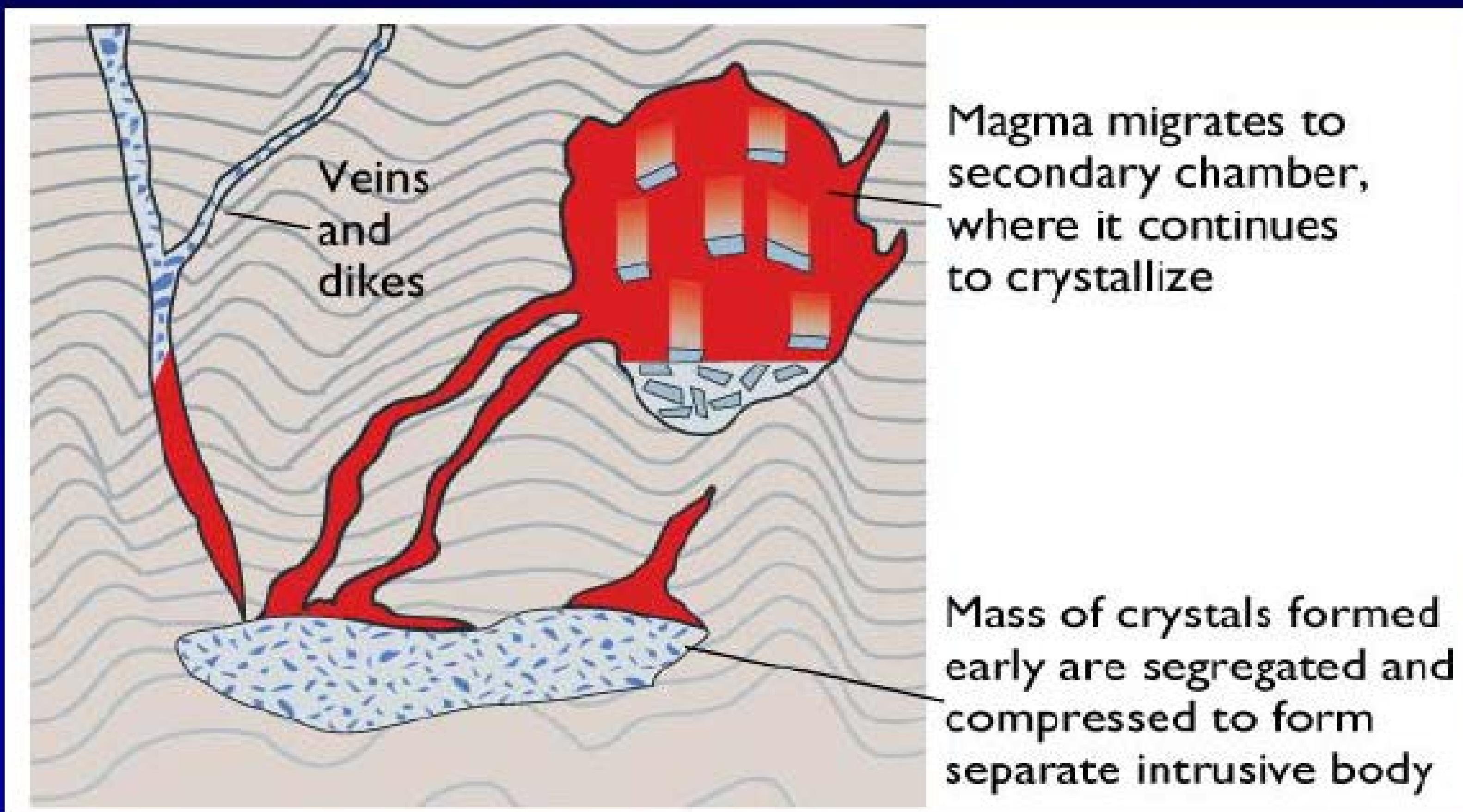
Example :

Basaltic magma + Rhyolite magma $\rightarrow$ Andesite

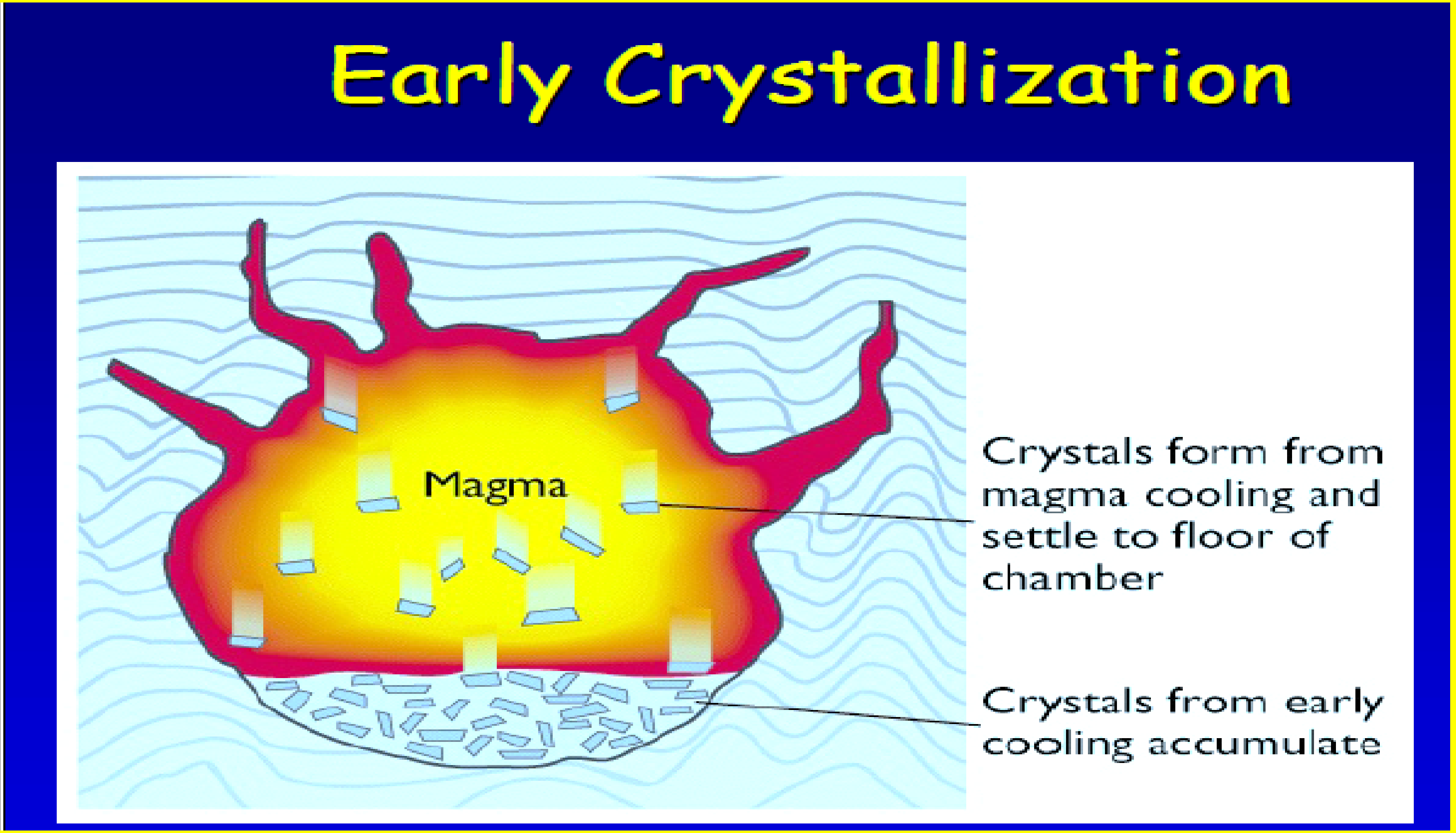
Basic	Acidic	Intermediate

1.Magma mixing

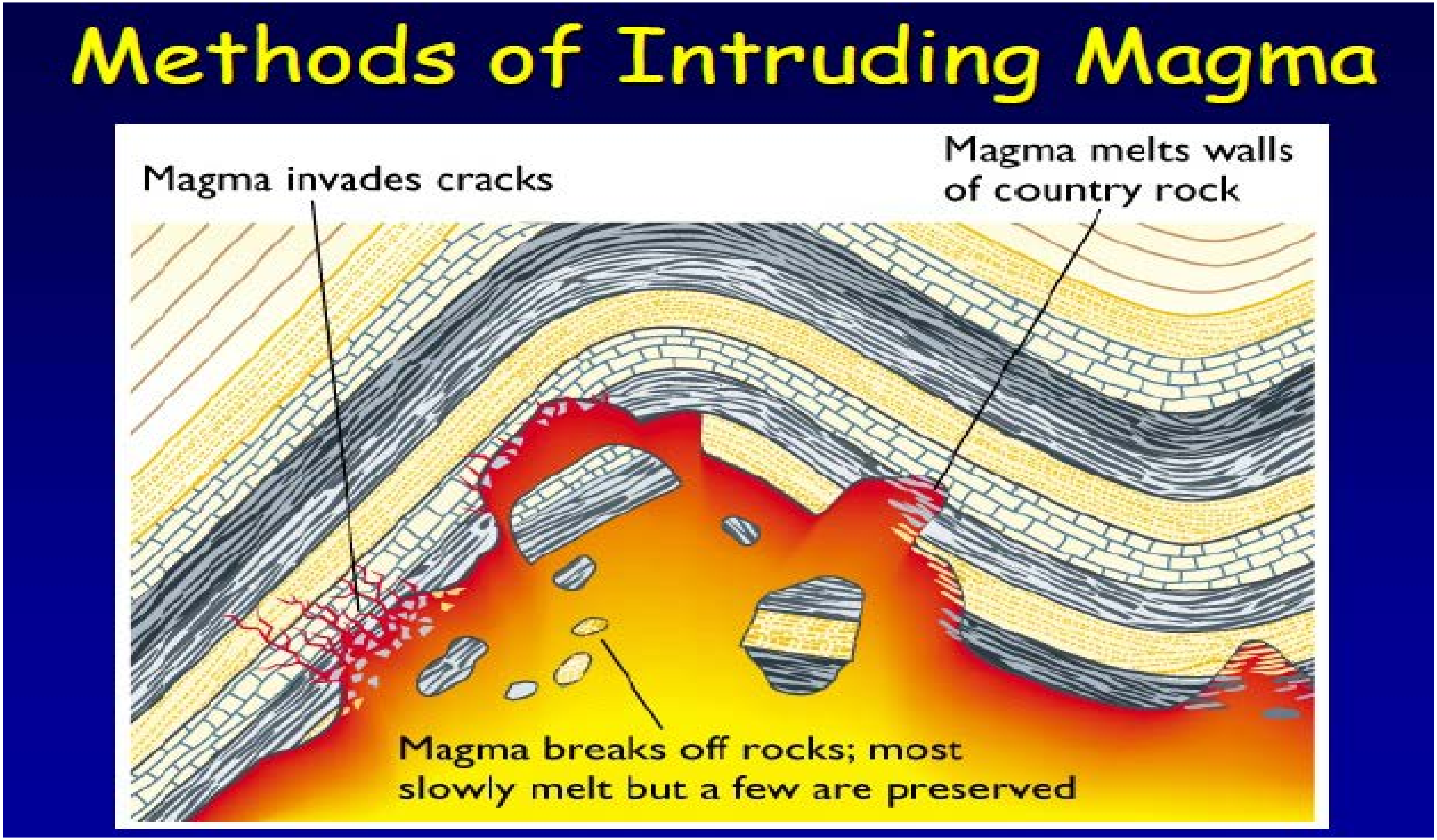
Liquids Squeezed from Crystals



2. Magmatic differentiation



3.Assimilation or Contamination



- **How Different Magmas Form?**

1.Factors effecting melting of rocks- thus create magma

a- Heat – radioactive isotopes, original Earth heat

b- Pressure – increases melting point of minerals/rocks

c. Water – lowers melting point of minerals

2. Fractional Crystallization (Magma Differentiation).

3. Magma – Assimilation,

4. Magma – Mixing

Classification of Igneous Rocks

Textures:

Aphanitic- crystals too small to see by eye

Phaneritic- can see the constituent minerals

Fine grained- < 1 mm diameter

Medium grained- 1-5 mm diameter

Coarse grained- 5-50 mm diameter

Very coarse grained- > 50 mm diameter

Porphyritic- bimodal grain size distribution

Glassy- no crystals formed

Classification of Igneous Rocks

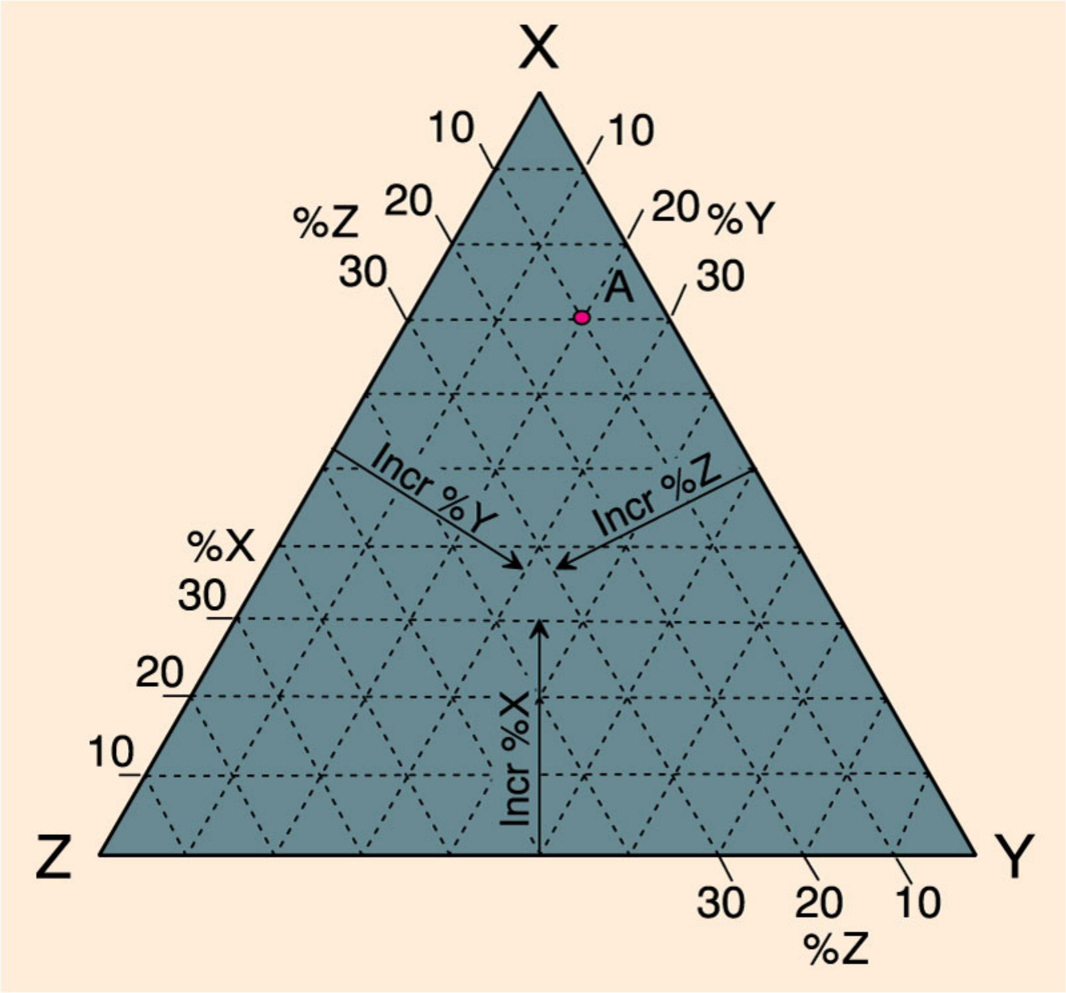


Figure 2.1a. Method #1 for plotting a point with the components: 70% X, 20% Y, and 10% Z on triangular diagrams. An Introduction to Igneous and Metamorphic Petrology, John Winter, Prentice Hall.

Classification of Igneous Rocks

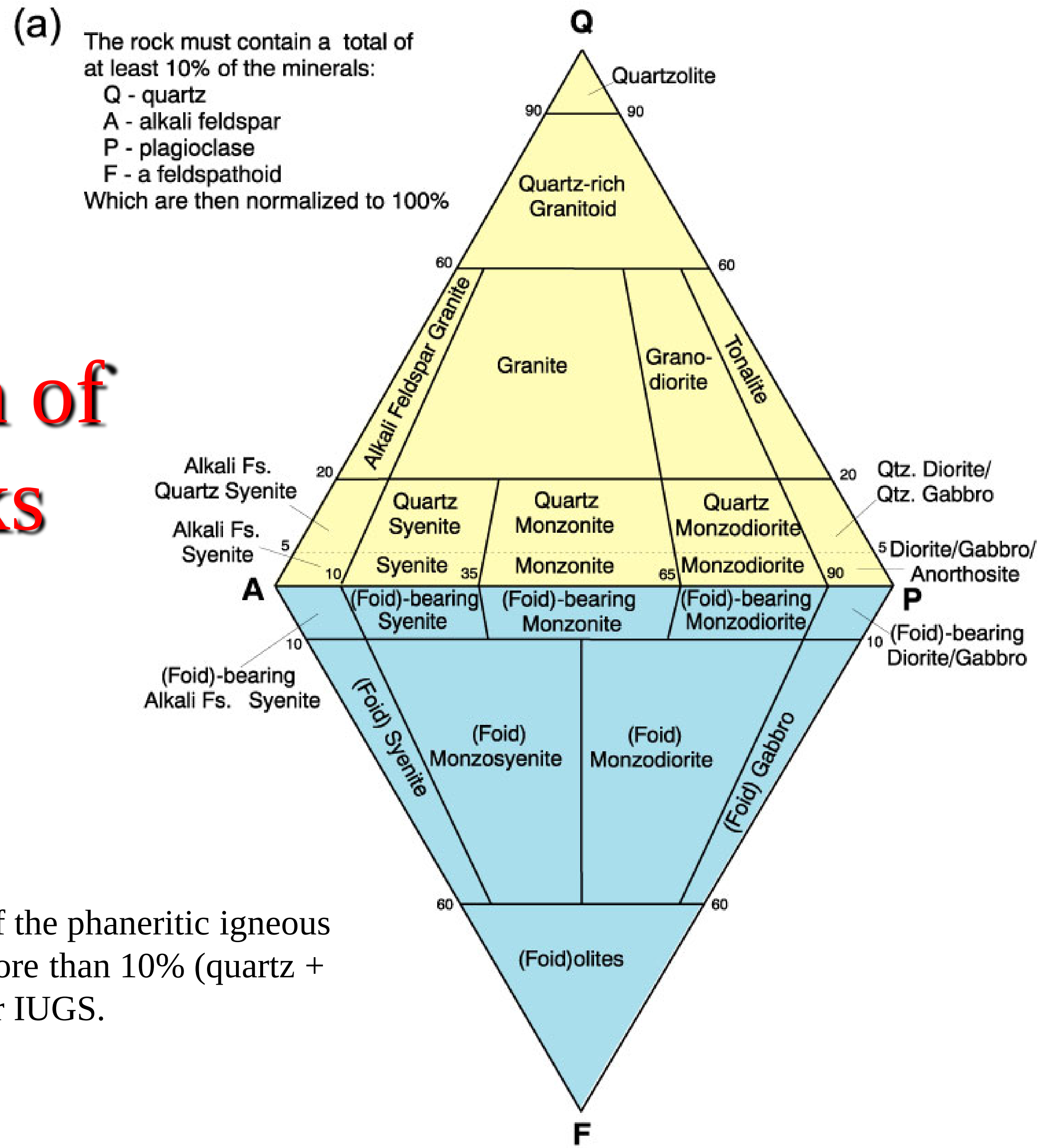


Figure 2.2a. A classification of the phaneritic igneous rocks: Phaneritic rocks with more than 10% (quartz + feldspar + feldspathoids). After IUGS.

Classification of Igneous Rocks

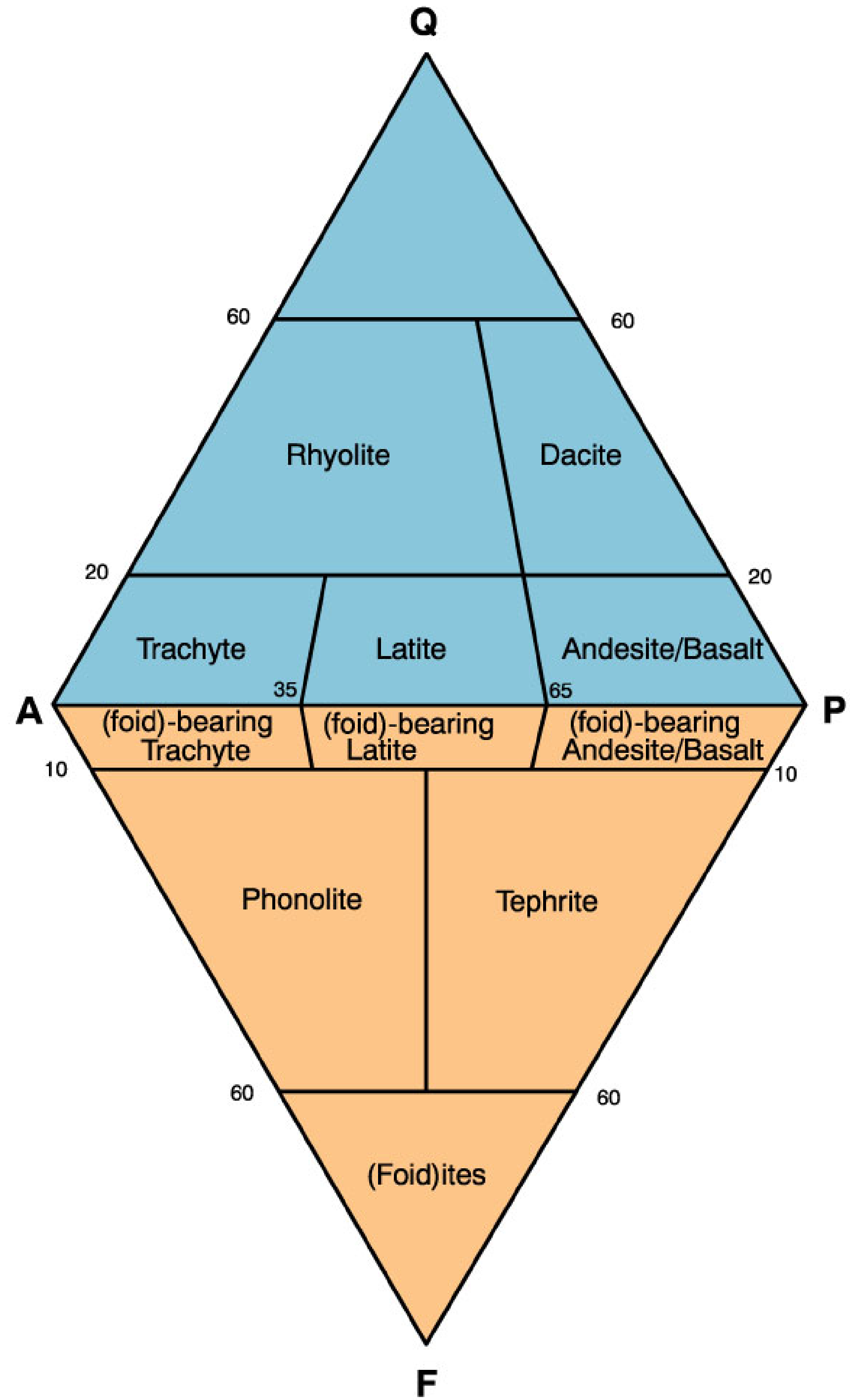


Figure 2.3. A classification and nomenclature of volcanic rocks. After IUGS.

Classification of Igneous Rocks

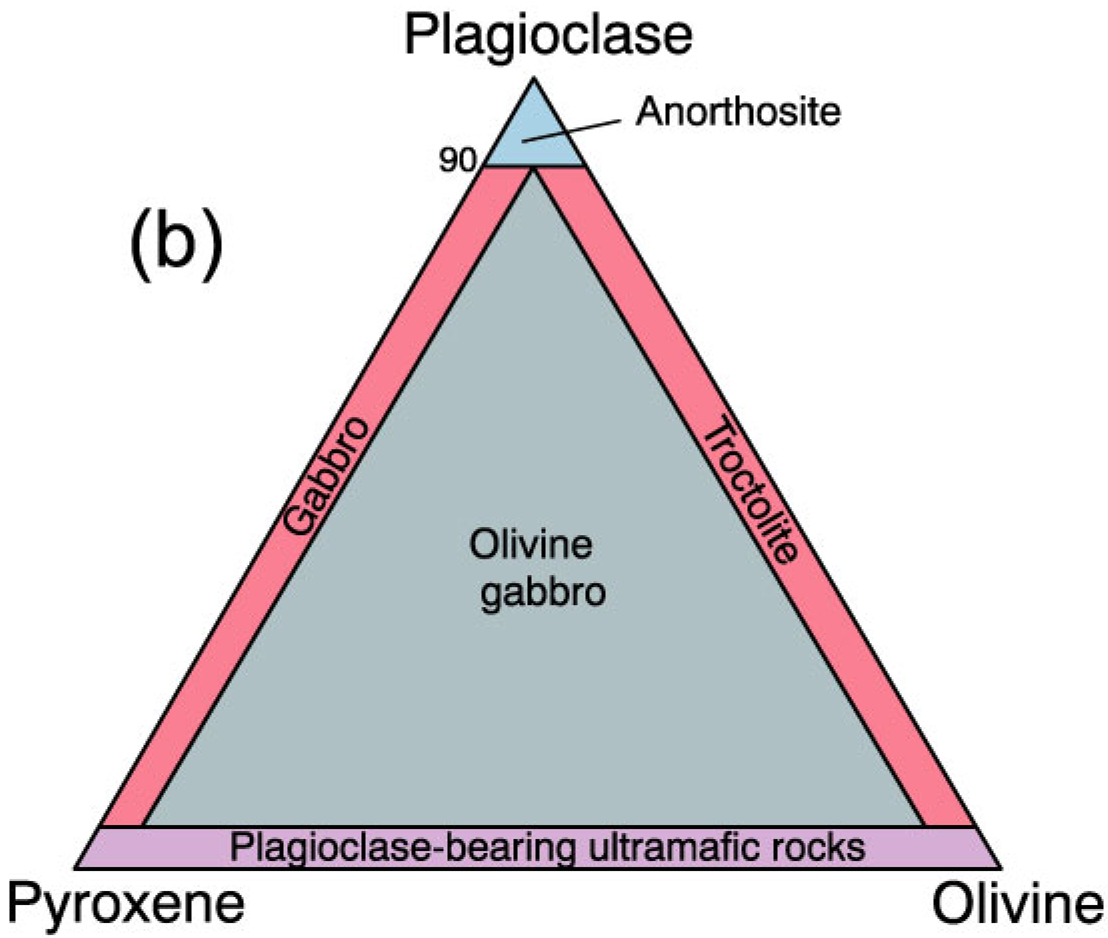


Figure 2.2b. A classification of the phaneritic igneous rocks: Gabbroic rocks. After IUGS.

Classification of Igneous Rocks

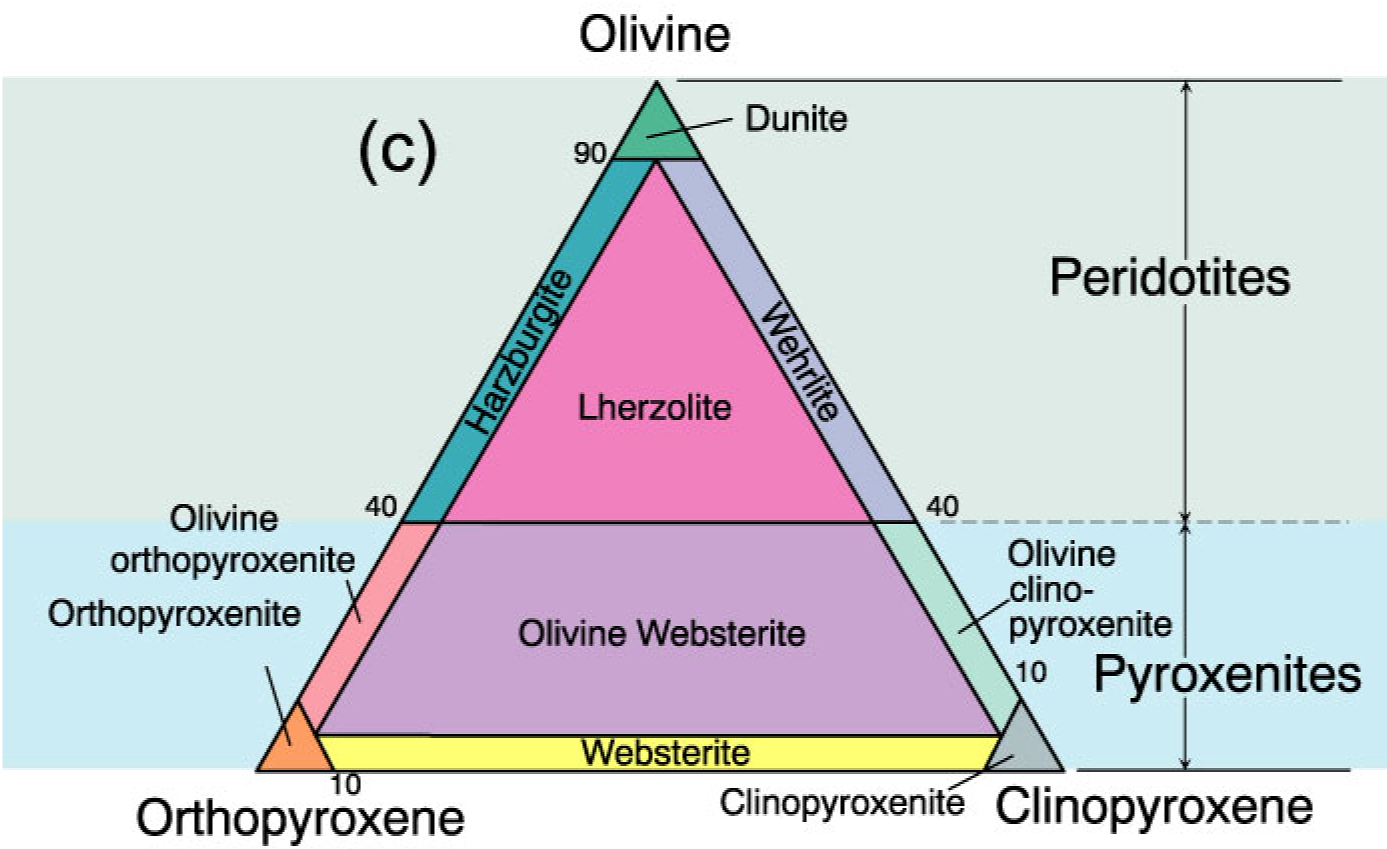
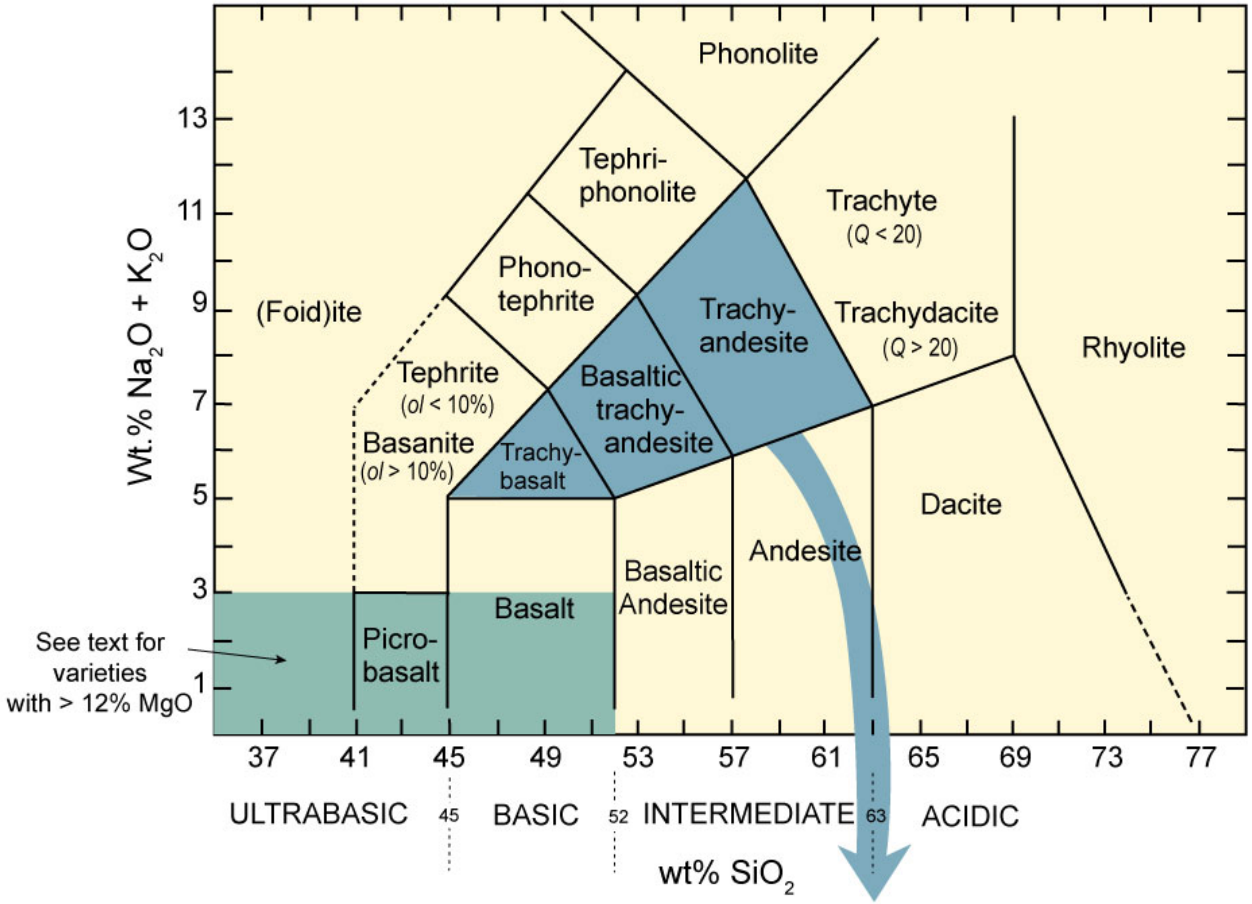


Figure 2.2c. A classification of the phaneritic igneous rocks: Ultramafic rocks. After IUGS.

Classification of Igneous Rocks



Further subdivisions of shaded fields	Trachybasalt	Basaltic Trachyandesite	Trachyandesite
$Na_2O - 2.0 \geq K_2O$	Hawaiite	Mugearite	Benmoreite
$Na_2O - 2.0 < K_2O$	Potassic Trachybasalt	Shoshonite	Latite

Figure 2.4. A chemical classification of volcanics based on total alkalis vs. silica. After Le Maitre (2002) . Igneous Rocks: A Classification and Glossary of Terms. Cambridge University Press.

Classification of Igneous Rocks

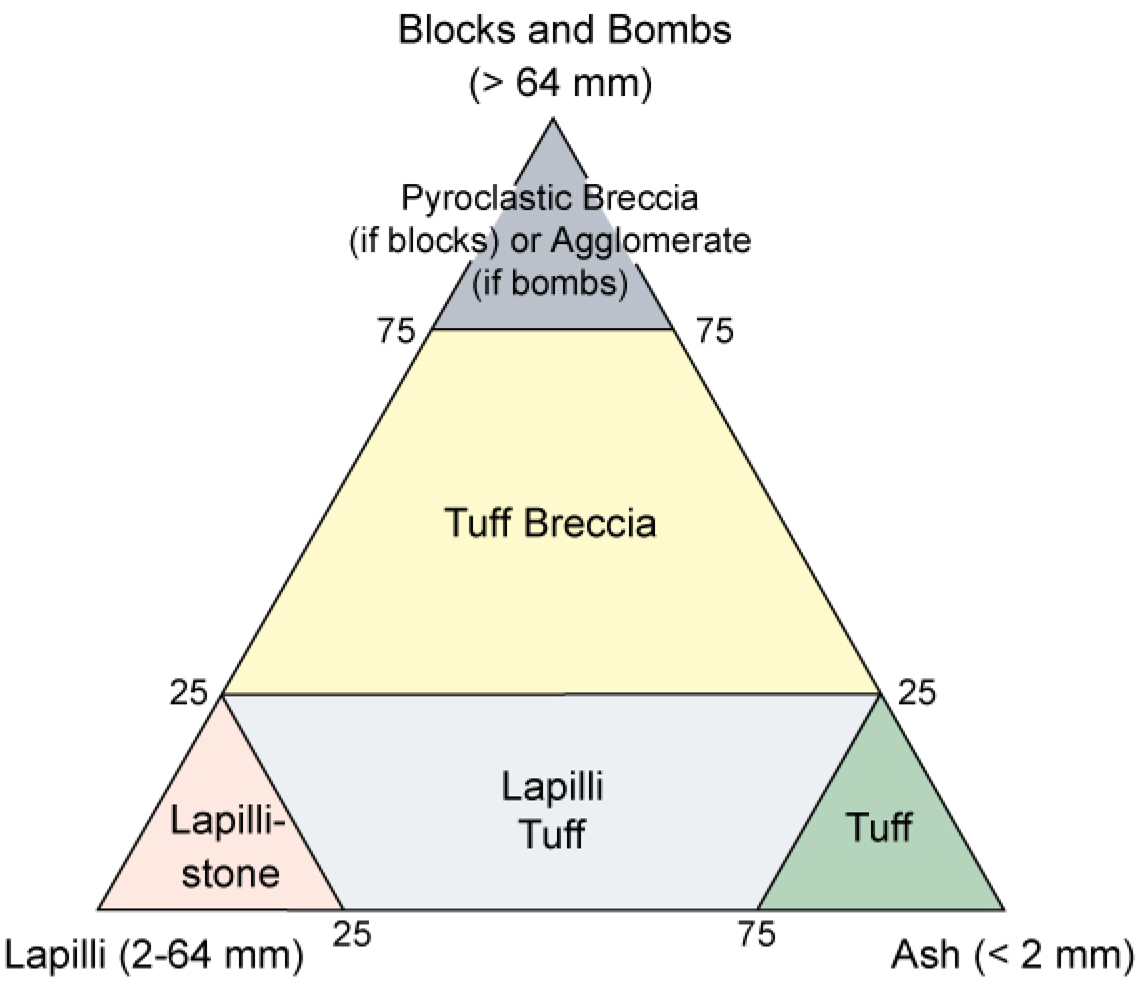


Figure 2.5. Classification of the pyroclastic rocks. After Fisher (1966) Earth Sci. Rev., **1**, 287-298.